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Comparison of ECT Probes in Diagnosis of Defects

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Abstract – In this paper, the characteristics of a defective elliptical aluminum plate are analyzed by three different eddy current testing probes; T/R, T/T, and Impedance probes. The analysis was done by 3D finite element method, and the impedance change of real and imaginary voltage values were analyzed.

Keywords: Eddy current testing probe, Finite element method, T/R probe, T/T probe, Impedance probe guidelines, Instructions, Prospective authors, Template

1. Introduction

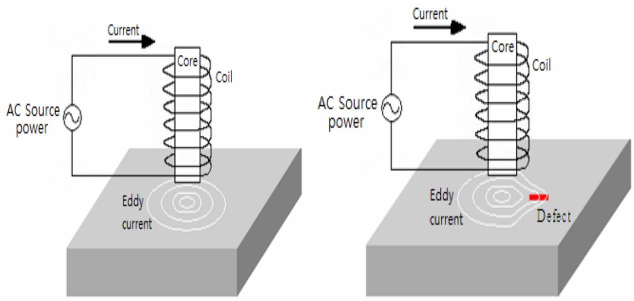
Nondestructive testing is one of the most efficient methods used to identify the material of a particle and to diagnose the safety condition. The Eddy Current Testing (ECT), in particular, is effective in determining the status of the surface abnormality of metals. There are many different types of eddy current testing probes, such as the Impedance probe, T/R probe, and T/T probe [1-4]. The number of uses of eddy current testing has been gradually increasing, so it has become necessary to analyze the characteristics and make comparisons between different types of probes. The aim of this research is to identify the characteristics of the ECT probe by using the Impedance, T/R, and T/T probes – which are normally used to identify abnormalities. In order to do so, we have designed the coil sensor and used the finite element method to compare the differences between the real and imaginary values of coil impedance from the eddy current testing.

2. Principles of Eddy Current Testing

2.1 Principles of eddy current testing

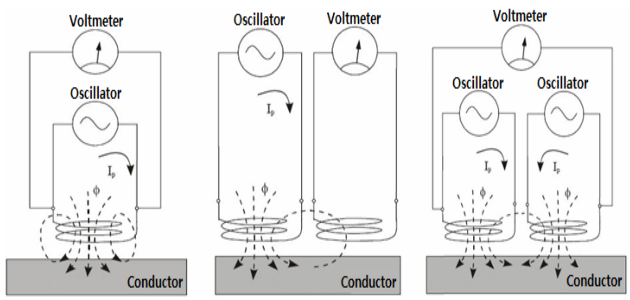
When the time-varying magnetic field of the coil is inserted into conductor, induced electromotive force is generated by Faraday's Law. This induced electromotive force generates the Eddy current then disturbs the time-varying magnetic field by Lenz's Law. A new time-varying magnetic field is created by this eddy current, and the synthesis of these two time-varying magnetic fields determines the total magnetic field interlinking the coil. As a result, the overall magnetic field varies the impedance of probe coil by changing the flow of the current. The change of impedance becomes one of the most important factors to grasp the state and the location of the defects inside a conductor tested. The effects of the defects on the magnetic equipotential lines are shown in Fig. 1.

There are two types of eddy current probes; one is the Transmit coil that generates magnetic field to eliminate eddy currents, and the other one is the Receive coil that detects the generated magnetic field to receive the sign as to whether there is a defect or not. In this paper, three kinds of ECT probes are studied; Impedance probe, T/R probe, and T/T probe. The Impedance probe is in charge of a single coil for Transmit/Receive, while T/R probe is responsible for two coils with Transmit/Receive coils for mutual induction. On the other hand, T/T probe is used only for Transmit. Fig. 2 and Table 1 shows three kinds of ECT probes and the functions of each coil.



(a) no defect (b) defect in the aluminum plate

Fig. 1. Principles of eddy current testing



(a) Impedance (b) T/R probe (c) T/T probe probe

Fig. 2. The equivalent circuit model of eddy current probe

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Table 1. Three kinds of eddy current probes

Probe	Function of coil
Impedance probe	Transmit / Receive
T/R probe	Transmit
	Receive
T/T probe	Transmit
	Transmit

2.2 An analysis of defects by impedance change

To verify the validity of the research, the analysis method was based on the analysis of existing model in former studies with conductivity 22.5 MS/m plate [5]. Also, the dimensions of the Impedance probe coil and defect are shown in Table 2, and the analytical model − a 3D model − is shown in Fig. 3. The defect used in the analysis is an elliptical shape. We have determined whether or not there was a defect by looking at the change in the impedance of coil when the probe moved steadily on the x-axis around the defect. Fig. 4 shows the analysis results by the proposed method. The impedance changes in the defect have different trends in real and imaginary values of the input frequencies. As the frequency increases the defect

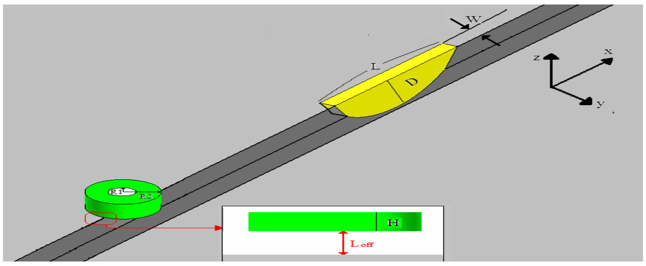


Fig. 3. Non-destructive testing model

Table 2. Dimension of non-destructive analysis model

Coil		Defect	
Inner radius R1	1.5 mm	Width W	0.33 mm
Outer radius R2	7.5 mm	Depth D	8.61 mm
Coil height H	3 mm	Length L	22.1 mm
Lift-off Loff		0.5 mm	
Plate thickness T		10 mm	
Coil inductance L0		100.47 μH	
Plate conductivity		22.5 Ms /m	

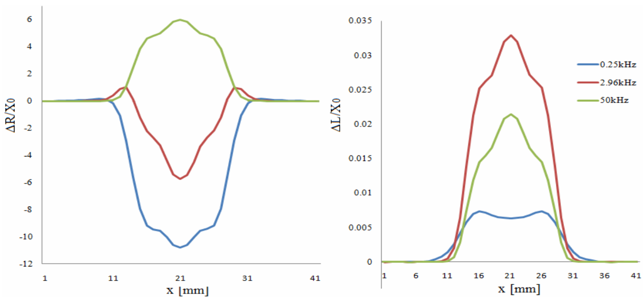


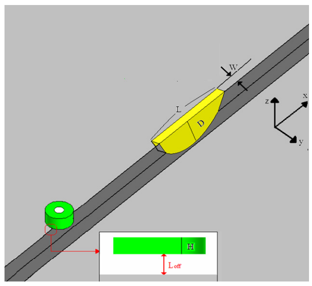
Fig. 4. The impedance changes in defects (flux interpretation)

signal moves in the complex impedance plane in a clockwise direction [5]. It confirms that the result is almost the same as that of the existing studies. In this thesis, non-destructive testing method was proposed and compared with the defect characteristics of the eddy current probe by using the 3D finite element method.

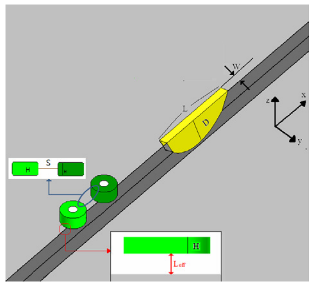
3. Defect Analysis by Different Eddy Current

3.1 Three kinds of eddy current testing model

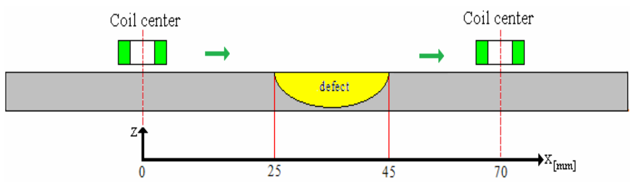
In the analysis, the aluminum plate with conductivity 33.445 MS/m was used as the conductor. The coil sizes of T/R and T/T probe were same. The dimensions of coil and aluminum plate are shown in Table 3. Lift-off of the probe is 0.45mm and coil spacing is 0.8 mm. The input current was selected as 0.28[A], frequency 8.75 kHz. Fig. 5(a), 5(b) show the 3D analysis model using the Impedance, T/T probe for ellipse-shaped defect [6]. Fig. 5 (b) shows the analysis region as the coil travels a distance of 70mm on the x-axis. The defect is placed in the direction of the x-axis. Two types of probes were used to identify the presence of defects. Table 4 shows the dimensions for the ellipse-shaped defect model in Fig. 6.



(a) Impedance probe



(b) T/T probe



(c) analysis region on the x-axis

Fig. 5. Analysis model

Table 3. Dimension of analysis model

Coil			
Inner radius R1	1.2 mm	Lift-off Loff	0.45 mm
Outer radius R2	2.4 mm	Coil height H	3 mm
Number of coil turns	80		
Coil spacing S	0.8 mm		
Coil inductance L0	17.73 μH		
Plate thickness T	3.2 mm		
Plate conductivity	33.445 Ms/m		

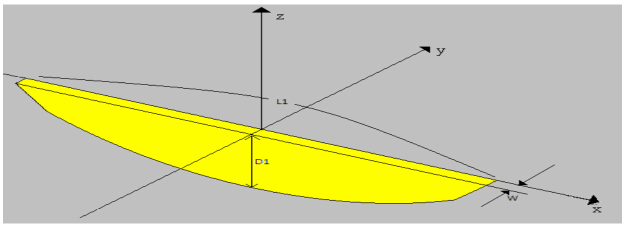


Fig. 6. Ellipse-shaped defect model

Table 4. Dimensions of defects

Defect model	Width W	Length L	Depth D
model a	0.1 mm	5 mm	1 mm
model b	0.1 mm	5 mm	2 mm
model c	0.1 mm	5 mm	3 mm
model d	0.1 mm	10 mm	3 mm
model e	0.1 mm	15 mm	3 mm
model f	0.1 mm	20 mm	mm

3.2 The analysis of elliptical defect model

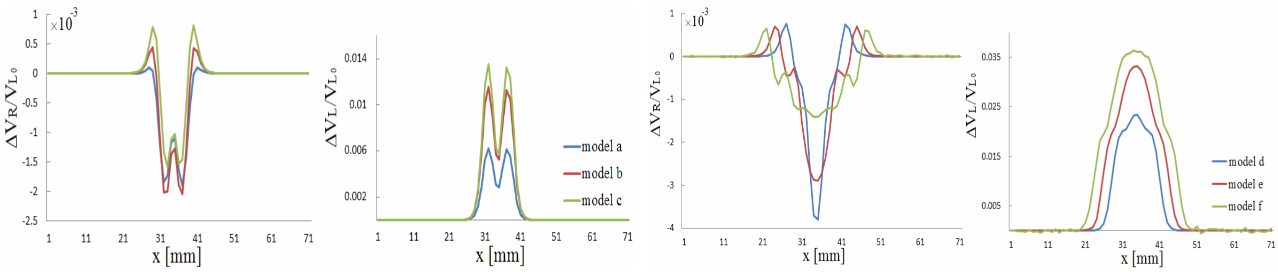
The analysis was done by 3-D finite element method, using one of the three types of probes that include defects and moving the Receive coil steadily on the x-axis. Fig. 7, 8, and 9 show the real and imaginary values of voltage drop of the probe coil in the ellipse-shaped defect and the magnetic equipotential lines.

Fig. 7 shows that the voltage drop varies as the depth and the length of the defect of the Impedance probe increases. Also, it shows that near the defect of the Impedance probe, the magnetic equipotential lines of the x-axis lean toward the defect of the Impedance probe.

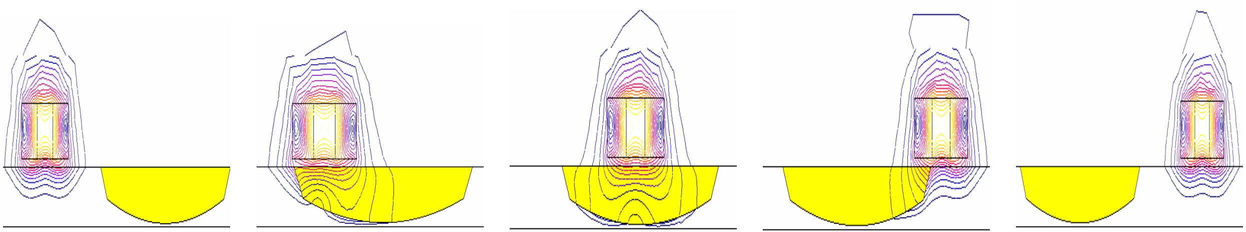
In Fig. 8, it is shown that the T/R probe gives similar maximum change in the imaginary value of the voltage drop if the defect has uniform length. Also, in the defect, the voltage drop changes because the magnetic equipotential line of the Transmit coil leans, which changes the total amount of the magnetic flux that intersects the Receive coil.

Fig. 9 shows that the longer the length of the defect of the T/T probe, the smaller the imaginary value of the voltage drop in the impedance. If the center of the coil is at the maximum length of the defect, the change of the voltage drop of the impedance reaches its maximum. However, the T/T probe identifies defects by the changes in the impedances of both coils. Thus, the T/T probe becomes 0 at the center, unlike the other probes. Fig. 9 (b) shows that the lean toward the center of the defect is not so great since the lean of the magnetic equipotential lines is a semi-circle when x=40.

All three probes' impedance changes and magnetic flux

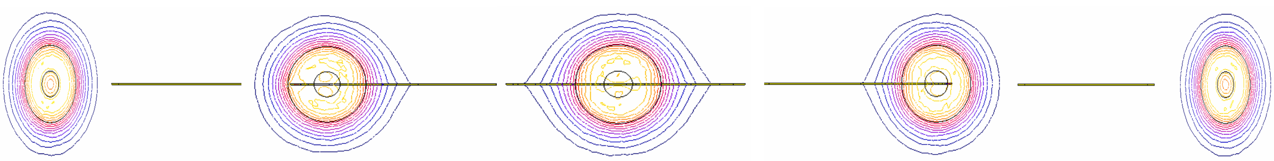


(a) Voltage drops in the resistor and reactor of probe coil at different locations on the x-axis



x = 15 x = 27 x = 33 x = 45 x = 54

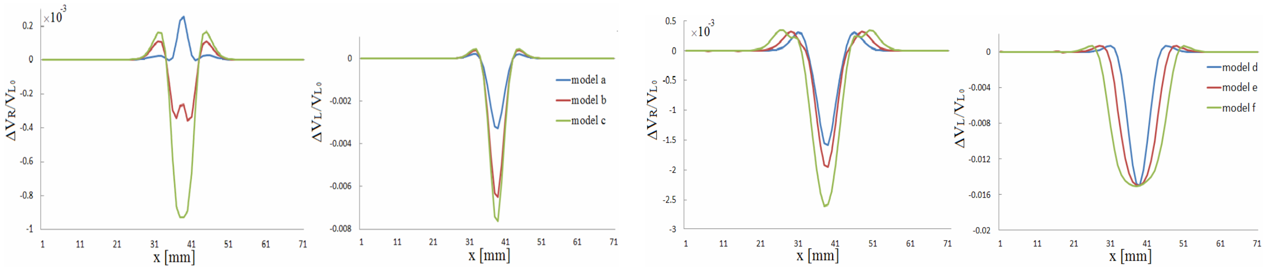
(b) Magnetic equipotential lines on the x-axis of model f during the coil movement



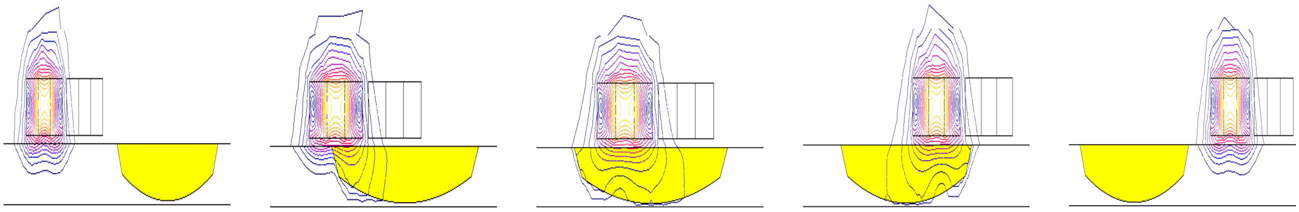
x = 15 x = 27 x = 33 x = 45 x = 54

(c) Magnetic equipotential lines on the z-axis of model f during the coil movement

Fig. 7. Impedance changes of impedance probe coil for an ellipse-shaped defect

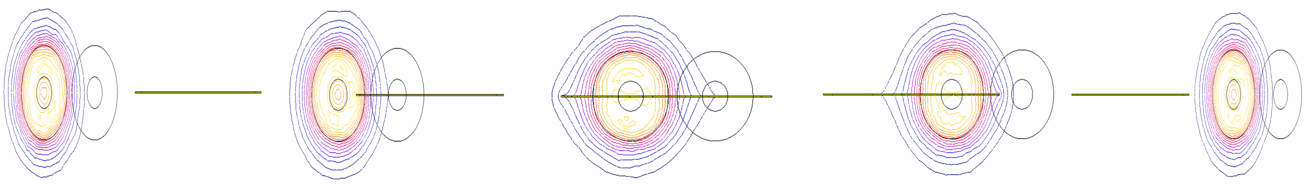


(a) Voltage drops in the resistor and reactor of probe coil at different locations on the x-axis



x = 17 x = 29 x = 38 x = 46 x = 59

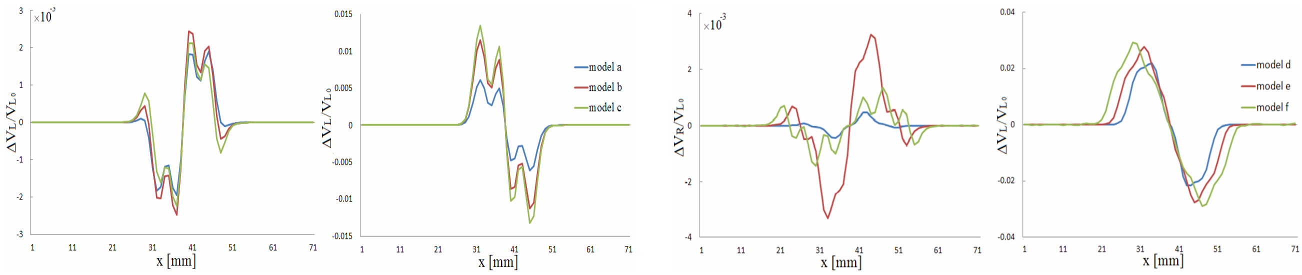
(b) Magnetic equipotential lines on the x-axis of model f during the coil movement



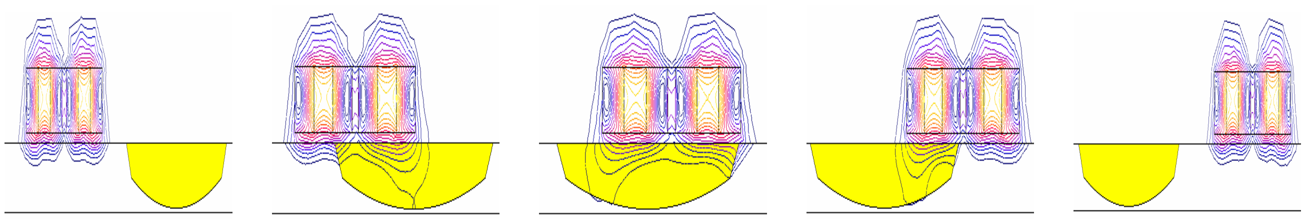
x = 17 x = 29 x = 38 x = 46 x = 59

(c) Magnetic equipotential lines on the z-axis of model f during the coil movement

Fig. 8. Impedance changes of T/R probe coil for an ellipse-shaped defect

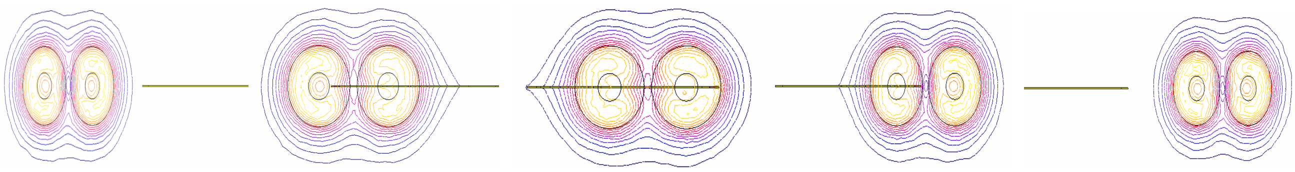


(a) Voltage drops in the resistor and reactor of probe coil at different locations on the x-axis



x = 15 x = 30 x = 40 x = 48 x = 60

(b) Magnetic equipotential lines on the x-axis of model f during the coil movement



x = 15 x = 30 x = 40 x = 48 x = 60

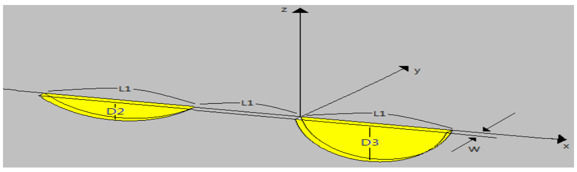
(c) Magnetic equipotential lines on the z-axis of model f during the coil movement

Fig. 9. Impedance changes of T/T probe coil for an ellipse-shaped defect

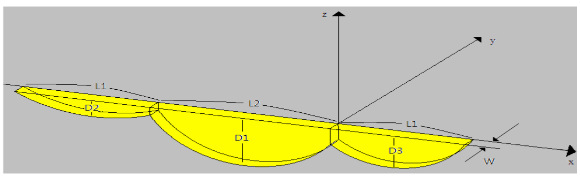
show equipotential line characteristics at the defect. The impedance change is affected if the equipotential lines are created at the defect, and the probe is seen to have a lean toward the defect. The magnetic equipotential lines have elliptical parts on the defect due to the increased lift-off of the probe. Also, the aluminum plate affects the strength of the eddy current. The strength of the eddy current determines the total amount of the magnetic field intersecting the Receive coil. Therefore, one can find out the presence of defects because the strength of the eddy current determines the total amount of the magnetic field intersecting the Receive coil – if the strength changes, the impedance of the Receive coil also varies.

3.3 Analysis results of double ellipse-shaped defect

The impedance changes of the elliptical defect of the probe were seen under the same conditions; the model for double ellipse-shaped defect and dimensions of the defect are shown in Fig. 10 and Table 5, respectively.



(a) defect model g



(b) defect model h

Fig. 10. Double ellipse-shaped defect model

Table 5. Dimensions of elliptical defect model

Defect model	Width W	Length L1	Length L2	Depth D1	Depth D2	Depth D3
model g	0.1 mm	5 mm	-	-	1mm	2mm
model h	0.1 mm	6 mm	8mm	3 mm	1mm	2mm

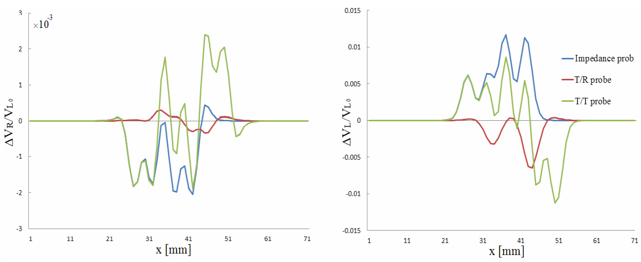
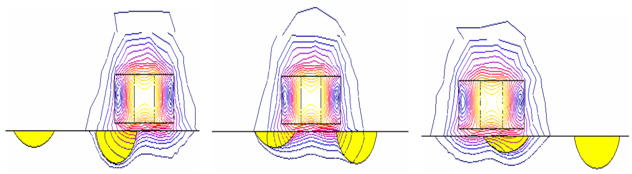
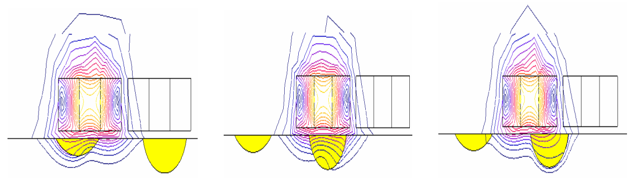


Fig. 11. Voltage drops in the resistor and reactor of probe coil at different locations on the x-axis for model g



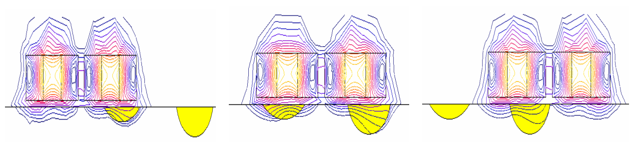
x = 27 x = 33 x = 42

Fig. 12. Magnetic equipotential line on the x-axis of defect model g for Impedance probe



x = 38 x = 43 x = 46

Fig. 13. Magnetic equipotential line on the x-axis of defect model g for T/R probe



x = 27 x = 37 x = 50

Fig. 14. Magnetic equipotential line on the x-axis of defect model g for T/T probe

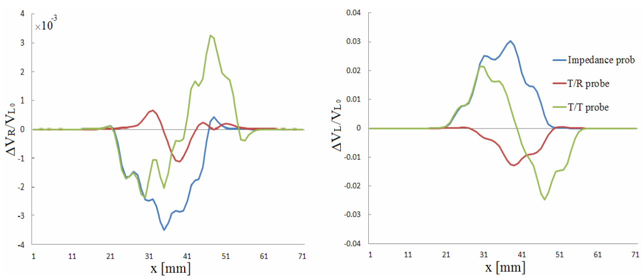
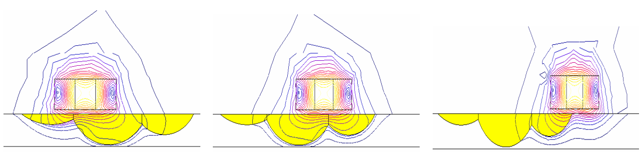
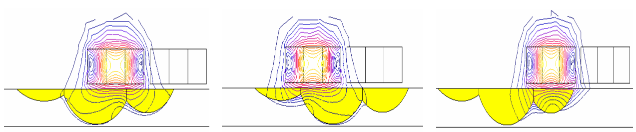


Fig. 15. Voltage drops in the resistor and reactor of probe coil at different locations on the x-axis for model h



x = 31 x = 37 x = 44

Fig. 16. Magnetic equipotential line in the x-axis of defect model h for Impedance Probe



x = 39 x = 44 x = 48

Fig. 17. Magnetic equipotential line in the x-axis of defect model h for T/R probe

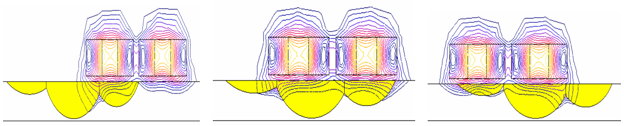


Fig. 18. Magnetic equipotential line in the x-axis of defect model h for T/T probe

In Fig. 11, the defect model g made by fusing defects a and b, represents irregular defect. At equal location on the defect, the Impedance and T/T probe show similar impedance change, but as they bypass the defect, one can see that in the Impedance probe the change in the impedance increases if many defects had existed and created more changes in the magnetic equipotential lines. In T/T probe, one can see that the magnetic equipotential lines are different if each coil had defects because the x-axis equipotential lines would have different values. From the results of model h, it can be seen that the more complicated the shape of the defect becomes, the more difficult it is to find symmetry of the impedance change of the probe. Compared to the Impedance and the T/R probes, the T/T probe is not symmetrical around the center of the defect if the defect has irregular length. The T/R probe shows a steady variance in the impedance change depending on the depth of the defect, but compared to the Impedance and the T/T probes the change is not as great. In comparison, the Impedance probe, unlike the other two probes, can easily find the location of defects because the impedance changes in proportion to the length and the depth of the defect, making the impedance change simpler to detect.

4. Results and Discussion

The probe identifies defects by the change in the impedance in each coil. Therefore, when the probe approaches a defect the changes of the impedances increases, and when it is at the center of the defect the impedances will have zero difference. When the T/T probe bypasses the center of the defect, a change in the impedance can be seen symmetrically around the center. The T/T probe detects defects by using the changes in the impedance in each coil. Therefore, when it is near the center of the defect the changes become greater, and when it is at the center the impedance becomes equal. This probe shows a symmetrical impedance change around the center of the defect. Compared to the other two probes, T/T probe does not have a good characteristic curve.

In the T/R probe, the changes in the impedance are consistent with the depths of the defect. However, the amount of change itself is smaller than the impedance changes shown in the Impedance and the T/T probes. The Impedance probe can easily detect the defects because the change of the impedance varies in proportion to the length of the defect. Therefore, the Impedance probe shows the greatest changes of the impedance among the three.

5. Conclusion

In this paper, three types of probes – Impedance, T/R, and T/T – that detects the depth, and length of the defect were analyzed using three-dimensional finite element method and different ellipse-shaped defects. We have looked for characteristics of the impedance changes and the magnetic flux equipotential lines. The result of the analysis shows that the Impedance probe is better than T/R, T/T probe in detecting the defects.

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