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Eddy Current Testing Technique to Detect Imperfection Surface for Different Lift-off Value on Copper Metal

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Abstract: ***Non-Destructive Testing (NDT) known as the evaluation of properties of a wide variety of materials without causing a damaged despite after inspection is done and the material still can be used. This paper aims for a designed NDT metal instrument that is conducted using eddy current testing (ECT) technique to find an applicable lift-off (LO) value in detecting imperfection. A dual sensor was designed consist of excitation coil was applied to evaluate the surface imperfections or other excitation frequencies in controlling the signal responses from the testing material, copper (Cu) with dimension of 100 mm x 100 mm installed with artificial surface imperfection (i.e., 7 mm, 14 mm and 21 mm) was main subject in this study. An established amplifier consisting of a specific op-amp was used to boost up the voltage of the alternate current (AC). The data of setting frequencies was ranged from 5.00 - 5.25 MHz was recorded varied of the LO values (i.e., 1.0 mm, 2.0 mm, 3.0 mm, 4.0 mm and 5.0 mm). Based on the frequencies applied the result for an applicable LO value acquires the promising result of reading signal was around 2 mm and the imperfection detection performance obtained a larger voltage gradient with the increase of the imperfection sizes. The study concludes that the developed non-destructive metal testing instrument of specific ECT design by using the excitation coil is appropriate in measuring the LO value and could be used to find different imperfection for metal.***

Keywords: ***Eddy Current Testing Technique, Lift-off, Metal Imperfection, NDT test.***

I. INTRODUCTION

Non-Destructive Testing (NDT) known as the assessing the properties of a wide variety of materials without causing a damaged despite having been performed and the material still can be used. Eddy Current Testing (ECT) is one of the techniques based on electromagnetic induction principle. It had been widely applied in various NDT instruments in the early 20th century and rapidly grow in industrial because of the user-friendly according to current developments and low cost of maintenance services. The noncontact, high-sensitivity and anti-interference capability of ECT system makes it important in many fields such as aerospace, metallurgy, electric power, machinery, nuclear and many more [1].

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This technology of ECT method used to ensure the quality control for inspection according to the standards and to keep maintenance. ECT used a non-contact detection on imperfection surface but due to work the effect of disturbance from errors of variations in the distance between the sensor and testing material, known as LO effect caused by uneven surface whenever the eddy current detection is difficult to analyse the originality of the actual imperfection signal. In the recent years, research about LO effect has been focused whether in the field of probe design, a signal from the perspective of rationality and detection strategy, this variety of instrument testing designed to improve the detection accuracy. One important part of the LO effect was the used of proper or suitable frequency to acquire the promising result in imperfection detection on the testing material. Several studies regarding the use of frequency for LO effect, for instance, [2] development of a dual-frequency eddy current system based on quantity interference devices in defect detection by choosing appropriate excitation frequencies, but this design used to decrease the variance of LO effects. In other research by [3], a design of the eddy current method by using the sine wave oscillator circuit and sensor circuit to acquire an optimal frequency for the metal testing instrument. However, this design only able to find the optimal frequency on defect detection without emphasizing the signal output of the LO effect. Another research by [4] in which the development of the test instrument using the LO intersection point is distinguish by the discrete harmonic content of the initial pulse representation of the Fourier series. In result, this design makes a signal response varied by the LO effect but less sensitivity of defect detection that used an absolute coil or single test coil. Another study on LO frequency by [5] design the eddy current measurement using the LO curve and using the cable that connects to a network analyser and a conventional eddy current probe instead of improving the design of the test coil to monitor the shot peening surface conditions. Howbeit, this design only focused on measuring of material property and detect the condition of surface material tested that was less considering on defect detection.

Aside from that, a study by [6] with design a reference phasor method based on reference voltage is proposed and implemented however this design makes only for suppressing the signal output of the LO effect on the probe coil voltage. Another study by [7] with design a magnetic field sensor (GMR sensor) under multi-frequency current excitation to analysed of amplitude and phase signals that allow the comparison of the different image quality strategies to show the defect even in presence of massive LO changes.

Hence, this study tried to find a suitable frequency using a dual sensor (receiver and excitation coil) to detect the output voltage of material testing. By using an amplifier, a specific op-amp to boost up the voltage of the alternate current (AC) source for measuring an appropriate LO value in detecting imperfection on selected material for specific eddy current design.

II. EDDY CURRENT TESTING

An eddy current testing (ECT) technique / method is used in various of industries to find measurements of imperfections, flaws or cracks. In general, the technique is used to estimate the internal structural condition of the material, to detect ground and surface defects, to detect fatigue cracks and to determine the position of cracks and geometric parameters such as metal sheet thickness or dielectric coating on metal products [8]. Therefore, its detection when eddy current encounters discontinuity in the test piece can be identified and used to describe the discontinuity that induces the shift in eddy current density.

There are several inspections and measurements with the eddy current methods that go beyond the scope of other techniques, including measurements of thin materials such as tubing and sheet stock. This is a useful tool to detect damage to corrosion and other damage that causes the material to thin. For example, in assemblies such as heat exchangers, the measurements used on aircraft fuselages skins and tubing walls. Besides, the ECT is also used to measure the thickness such as paints and other coatings. The eddy current equipment and probes could be acquiring in a various of configuration like eddy scopes, conductivity tester, computer system for data manipulation, signal processing software, impedance analyzer and a few portable scanning for special applications. The design and test parameters of the probe must therefore be defined with the good knowledge of the imperfections to be found in order to make the measurements accurate and could be implemented.

A. Lift-off

The lift-off (LO) of eddy current testing technique describes a change in impedance that occurs when the distance between the inspection coil probe and the test piece varies. The change of the LO will be influence in the analysis result, since the large LO noise changes the signal phase much from the probe, the signal phase can hardly be used to evaluate imperfection or flaws. In other words, the distance between the probe and metal must be as constant as possible to avoid the effect of LO, but since this effect known as a source of noise in many applications and is an undesirable parameter in imperfection detection, hence determine an appropriate LO effect will contribute to optimizing the application of the coil design and the sensor array for certain instrument. The calibration signal of LO effect method shown as Figure 1. The LO variance is important for different distances between the test probe and the test piece under inspection resulting in a change in the distribution of eddy currents within the material and therefore a change in the signal obtained by the eddy current sensor [7]. This is happening when variations of LO caused by different characteristic of coating thickness and imperfection of sample surfaces or operator's movements for instrument. Throughout impedance analysis will carry out the signal indication that appropriate with the probe's instrument [9].

III. METHODOLOGY (EXPERIMENTAL SETUP)

A. System of Eddy Current Testing (ECT) Technique

Eddy current testing (ECT) technique was based on the relationship between the impedance of the probe and the electrical properties of the material, an eddy current technique to determine the optimum LO as shown in Figure 1.

A dual-sensor consists of excitation coil and receiver coil will be used to detect the output voltage of copper metal that is installed by an artificial imperfection surface. This inspection was used an established amplifier, a specific op-amp to boost up the voltage of the alternate current (AC) source with applied different range of desired frequencies between 250 kHz to 7.0 MHz by using the function generator. The LO between the test sample and the test material surface has a strong influence on the obtained voltage or magnetic field signal measurement signals. This happens when high-frequency AC enters the primary coil that produces the eddy current [3].

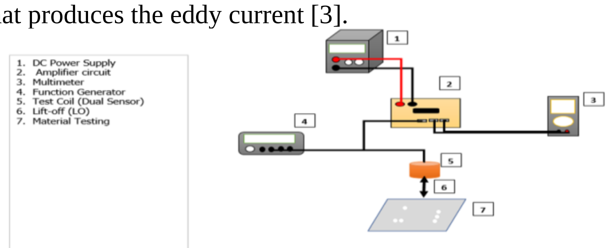

Fig. 1. Schematic diagram of the eddy current testing technique system.

B. Testing Material

Copper with different artificial imperfections, *h* (i.e., 7 mm, 14 mm, and 21 mm) was used as the testing materials in this study as shown in Figure 2. To evaluate the different imperfection for this material, dual sensors with circular air-cored coil or wire winding as ring shape was used. Table 1 shows the specification of this coil and Figure 3 and Figure 4 shows the configuration and geometry of this testing coil.

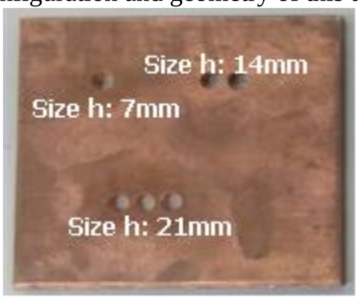

Fig. 2. Testing material (Copper) with a different imperfection surface (i.e., 7 mm, 14 mm and 21 mm) for 1.5 mm thickness.

Table 1. Specification of the material testing probe

Probe Type	Turns (Receiver coil), N	Turns (Excitation Coil), n	Inner diameter, d (cm)	Outer diameter, D (cm)	Length, *l* (cm)
Dual sensors	**80**	**100**	**0.5**	**1.0**	**1.0**

C. Lift-Off (Distance between the Probe and Conductive Material Coupling)

All Eddy current testing technique is based on the electromagnetic principles and using a simple electronic circuit to construct the eddy current measurement of the materials as shown in Figure 3, the eddy current probe with inductance L_1 and the current loop in the material with L_2 and resistance R respectively. When the imperfection disturbed the eddy current flow, the coil impedance was changed and by measuring these impedance changes or resultant magnetic field using a coil sensor, the imperfection in the test material had potential to detect.

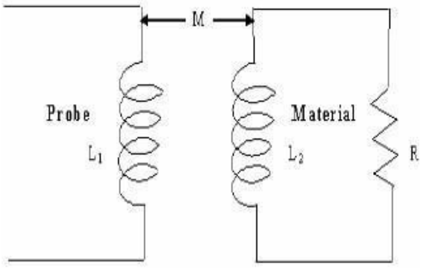

Fig. 3. Circuit model for the eddy current [10]

The mutual inductance between the coil and material is closely related to the distance between the probe and the material, as the efficiency of the probe sensor becomes lower as the LO increases. The paired of mutual inductance, M:

$$M = k\sqrt{(L_1 L_2)} \qquad (1)$$

k is the coupling factor which depends on the sample design spacing between the sample and the material. Different values vary from 1 mm to 5 mm.

The normalized impedance of probe is:

$$\frac{Z}{Z_0} = 1 - \frac{K^2}{1 - jR/(\omega L_2)} \qquad (2)$$

II. EXPERIMENTAL RESULT AND COMPARISON

A. The Suitable Frequency for Eddy Current Testing Technique

Keep Eddy current method was used in detecting metal imperfection to study the differences of imperfection in copper metal. The sample with a dimension of 100 mm x 100 mm x 1.5 mm $100\ mm \times 100mm \times 1.5\ mm$ had been drilled with different imperfection artificial on the surface as shown in Figure 2. The frequencies applied is between 1.00 MHz to 6.00 MHz and then the output signals were plotted in a graph to compare the differences of imperfection varied by variation of frequencies. The analysis of experimental data was consisting of:

a) Analysis of the output signal at various frequencies to determine the optimum inspection frequency. In other words, the frequency at which the output signal was maximized is assumed to be the appropriate one, even if, due to the presence of environmental noise and noise caused by the LO variations, it could not correspond to that previously measured for the given setup.

b) The comparison of the output signal value obtained at a suitable frequency by different LO variations enables the optimal output signal in terms of defect detection to be established.

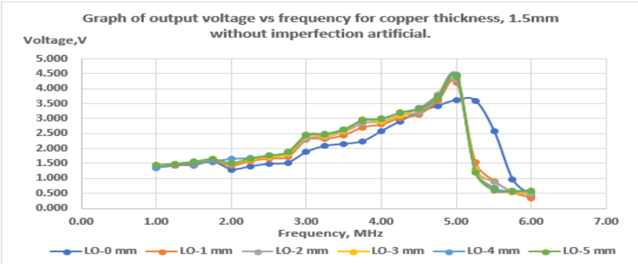

Fig. 4. Signal output voltage without imperfection surface varied by various frequency for copper metal thickness, 1.5 mm.

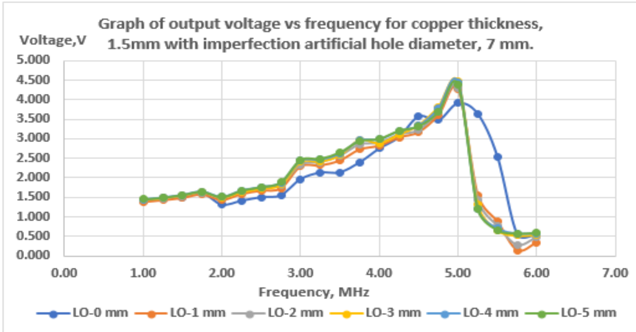

Fig. 5. Signal output voltage with imperfection artificial width, 7 mm varied by various frequency for copper metal thickness, 1.5 mm.

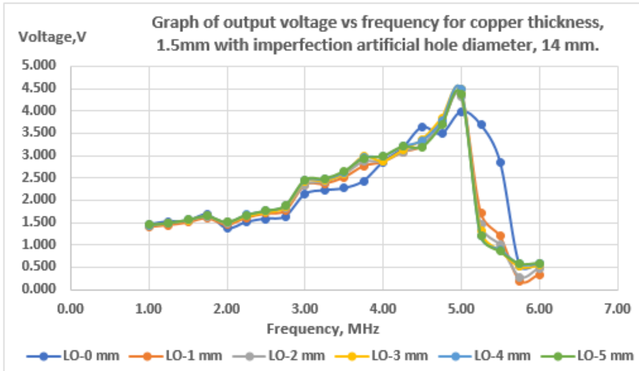

Fig. 6. Signal output voltage with imperfection artificial width, 14 mm varied by various frequency for copper metal thickness, 1.5 mm.

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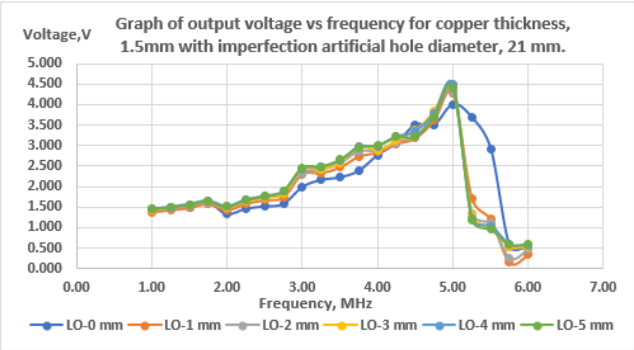

Fig. 7. Signal output voltage with imperfection artificial width, 21 mm varied by various frequency for copper metal thickness, 1.5 mm.

Using the experimental set-up as shown in Figure 1, several magnetic fields were generated by using the dual sensor of a circular air-cored coil. Whilst, for the distance of the dual sensor coil, was located at the top from the testing material as illustrated in Figure 4 namely as LO values (i.e., 1.0 mm, 2.0 mm, 3.0 mm, 4.0 mm and 5.0 mm). The suitable frequency for the testing material then implemented on three different kinds of imperfection surfaces was plotted in the graph. The output voltage was measured, then the responses signal of the various imperfection surface varied by frequency were compared and analysed based on the application of LO effects as the result shown in Figure 6. This collection of experiments was carried out by collecting data for the three imperfect surfaces with no LO value, which was considered the best measurement since there was no LO variance. From the graph in Figure 4, 5, 6 and 7, the frequencies range obtained between 5.00 MHz to 5.25 MHz as shown the obvious responses signal. In this method, the excitation coil was used against the material by circulating current in the inductive coil and the receiver coils act as the sensing parts to create an induced voltage.

According to the study by [7] which claimed that different frequencies cross with different speeds, higher frequencies spread more quickly with a limited depth whereas lower frequencies have depths of penetration with extended dispersion times. Thus, the computation of the optimal previous frequency of inspection depends on the type of sensor used, the type of imperfection surface and testing material which is related to the spatial distribution of the eddy current. Similar to the study by [11] in which the operating frequency has little impact on the results in the frequency range inspected. Instead, it was discovered that the location of the coil position had an abrupt effect during scanning on the voltage variations. Thus, the locations of the sensor coil can be optimized to enable the best sensing of voltage variations when the probe passes over the surface of imperfection.

B. Detection Imperfection on the Testing Material

The output voltage was measured between the signals responses for LO variation was compared the result obtained based on three different kinds of imperfection surface detection as could be seen in Figure 8 and 9, whilst for the Table 2 shown that the result of signal output voltage for different imperfection hole diameter and various LO values. It is shown that the output voltage varied by imperfection surface was increased according to the variation LO values when tested under frequency at 5.00 MHz as shown in Figure 8 and for the frequency at 5.25 MHz shown that result of output voltage decreased according to the LO values as illustrated in Figure 9. Whilst, for certain frequency the signal response may not run properly due to some error such as the presence of environmental noise and caused the output voltage has fluctuated.

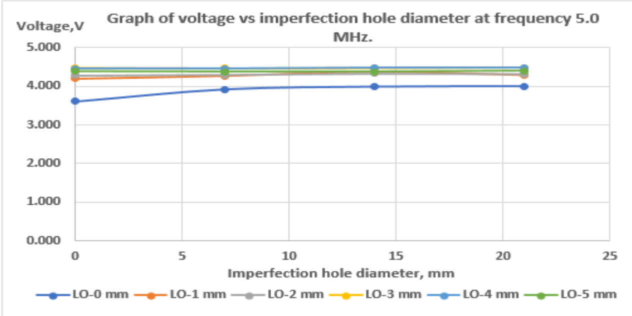

Fig. 8. Signal output voltage with different imperfection hole diameter varied by various frequencies for copper at frequency, 5.00 MHz (LO-1 mm=1.0 mm, LO-2 mm = 2.0 mm, LO-3 mm = 3.0 mm, LO-4 mm = 4.0 mm and LO-5 mm = 5.0 mm).

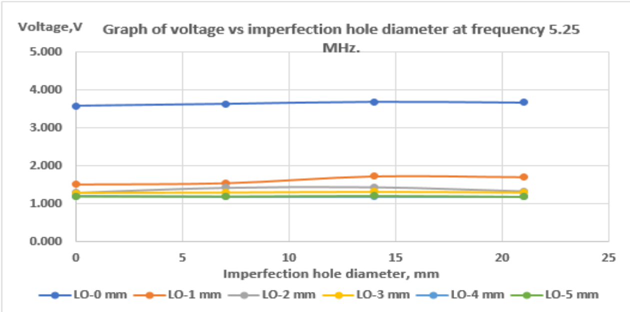

Fig. 9. Signal output voltage with different imperfection hole diameter varied by various frequencies for copper at frequency, 5.25 MHz (LO-1 mm=1.0 mm, LO-2 mm = 2.0 mm, LO-3 mm = 3.0 mm, LO-4 mm = 4.0 mm and LO-5 mm = 5.0 mm).

From previous research by [1] found that the influence of the sensor coil on the imperfection detection performance obtained a result was a larger voltage gradient with an increase of the imperfection sizes. This result as shown in Figure 8 which was tested under frequency 5.00MHz.

Table 2. Result of signal output voltage for different imperfection hole diameter and various LO value (LO-1 mm=1.0 mm, LO-2 mm = 2.0 mm, LO-3 mm = 3.0 mm, LO-4 mm = 4.0 mm and LO-5 mm = 5.0 mm).

Frequency, MHz	Imperfection hole diameter, mm	LO-0 mm	LO-1 mm	LO-2 mm	LO-3 mm	LO-4 mm	LO-5 mm
5.00	0	3.612	4.200	4.280	4.480	4.460	4.390
	7	3.920	4.270	4.300	4.470	4.460	4.380
	14	3.989	4.370	4.330	4.480	4.480	4.380
	21	4.002	4.290	4.320	4.490	4.480	4.410
5.25	0	3.591	1.529	1.307	1.295	1.207	1.200
	7	3.645	1.559	1.435	1.307	1.197	1.200
	14	3.701	1.729	1.450	1.327	1.197	1.220
	21	3.678	1.710	1.345	1.305	1.197	1.190

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C. Optimum LO of Eddy Current Testing Technique

Based on that frequency responses in detecting metal imperfection were used to find out an appropriate LO value for applied in the eddy current testing technique instrument. A sample of copper metal with a different hole diameter of imperfection surfaces was used for the testing instrument with selected frequencies were 5.00 MHz and 5.250 MHz, whilst the LO values used namely as LO-1 mm =1.0 mm, LO-2 mm = 2.0 mm, LO-3 mm = 3.0 mm, LO-4 mm = 4.0 mm and LO-5 mm = 5.0 mm. Then the output signals were plotted in a graph as shows in Figure 10 and 11 to compare the result. As refer to study by [12] found that a small variation of LO will yield an insignificant change in signal response, but it is important to get an optimal signal response with an appropriate LO value. For this study, the signal responses based on the result of the output voltage. As refer to [13] the signal produced will be decreased rapidly with increased of LO value, then made change rates of resistance and inductance are reduced as the LO value increased. This result shows in Figure 11 which was tested under frequency 5.25 MHz.

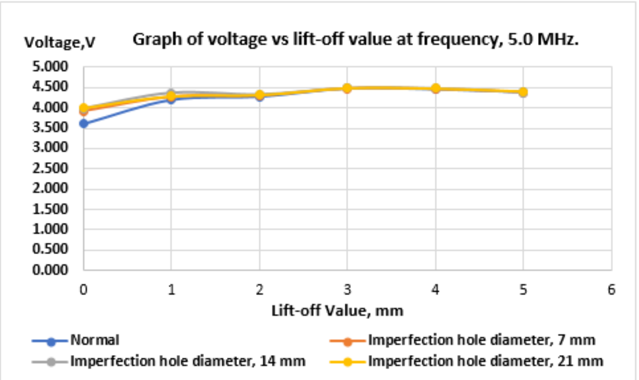

Fig. 10. Signal output voltage with different size of imperfection surface varied by various LO values for copper metal at the frequency, 5.00 MHz.

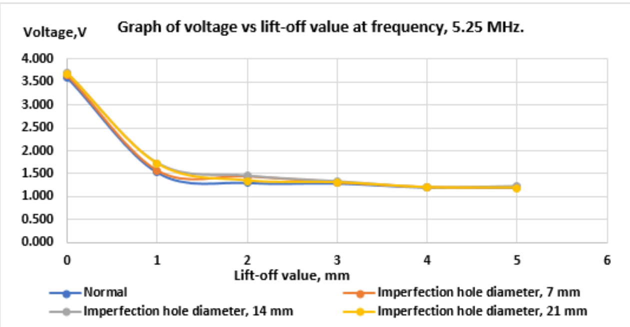

Fig. 11. Signal output voltage with different size of imperfection surface varied by various LO values for copper metal at the frequency, 5.25 MHz

From the graph of different imperfection surface exhibit, the relation for various lift-off LO values where the received signal supposed to be reduced rapidly with increased of LO value as shown in Figure 10 and 11, and detection of imperfection surface for frequency at 5.25 MHz obtained an appropriate LO value was around 2 mm as shown in Figure 11, while at 4 mm and 5 mm, the reading of the output voltage signal was constant. Based on previous research by [12] that is also discover about 2 mm LO value for its inspection result which is used the electromagnetic acoustic transducer (EMAT) driven by a 20A sinusoidal current at frequency value was 250 kHz. Although, different in frequencies but it depends on the sensor used as stated by [14] in measuring the LO effect and imperfection surface detection influenced by its frequency excitation used which are higher frequency used for measuring the LO, while the lower frequency used for imperfection detection and sized. Besides, the different of the LO value obtained may cause by the frequency applied whenever increasing the frequency, the magnitude of eddy current increases as obtained by a reading of output voltage signal [11].

III. CONCLUSION

The purpose of this research to determine an appropriate LO value for application to detect the imperfection on the testing material was copper metal by using non-destructive testing known as eddy current testing technique. There were results acquired by the response for each LO values that inspected on different sizes of imperfection surface or hole diameter of the metal used. This testing instrument was used 50 ohms ground of function generator to inspected. It was found that the frequencies between 5.00 MHz to 5.25 MHz showed the most obvious responses but the suitable frequency for inspection was 5.00 MHz for this kind of inspection imperfection surface and for measuring LO value the suitable frequency was 5.25 MHz. For this research, it was found that the application LO value for this kind of inspection was around 2 mm and imperfection detection performance obtained a result was larger voltage gradient with increase of the imperfection sizes, then it could be concluded that this type of testing instrument of eddy current method could be implemented to find different defects on the non-destructive metal tests.

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Elnetthra Folly Eldy is currently a lecturer in Universiti Malaysia Sabah teaching Physics for pre-university students. She graduated from Universiti Malaysia Sabah for her BSc in Physics with Electronics in 2011 and her MSc in Educational Technology on 2015. Her current interest in research is about student-centered learning, problem-based learning in a higher education institution and blended learning in higher learning. Her latest work is entitled Inverted Classroom Improves Pre-University Students Understanding On Basic Topic Of Physics: The Preliminary Study published in the Journal of Technology and Science Education, Optimisation Frequency for Different Lift off on Aluminium using Eddy Current Testing (ECT) Technique published in Transaction on Science and Technology both in 2019.