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Optimisation Frequency for Different Lift off on Aluminium using Eddy Current Testing (ECT) Technique

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ABSTRACT One of the main hindrances of Eddy-current Testing (ECT) technique is the lift-off (LO) effect which it can easily mask defect signals. This paper is an ongoing study on analysing the optimum lift-off value distance for specific design of ECT technique theoretically and experimentally. Through this approach, the detection of imperfections was determined by the slope of the peak value of the different frequency varied by various lift off values and was verified by experiment with an established circuit. This circuit is efficient and could be used with different range of desired frequencies (i.e., 250 kHz -3.5 MHz) by using a function generator and an established probe consists of excitation coils and receiver coils known as dual sensors device. Result obtained from the output voltage signal at higher frequency becomes much lower as the lift-off distance increases. It showed that the signal responses for measuring the various lift-off values, whilst at certain lower frequency could not been detected, however convenient for detect imperfections. Throughout this, the applicable lift-off distance that used to detect imperfection for aluminium with different imperfection sizes was 3 mm for frequency 2.65 MHz, 2 mm for frequency 2.75 MHz, 1 mm for frequency 2.85MHz, and 0 mm for frequency 2.95MHz. It can be concluded that, using higher excitation can be used to measure suitable lift-off, however lower frequency can be used to detect imperfection including its sizes.

KEYWORDS: Eddy-current testing, Lift-off effect, imperfection; aluminium; frequency
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Full Article

INTRODUCTION AND BACKGROUND THEORY

Non-destructive evaluation (NDE) techniques based on electromagnetic methods are usually used for inspection of material such as metallic materials that widely used in modern engineering as constructional materials. For instance, imperfections are one of the most attractive and exciting field of engineering such as aviation and aircraft industry where the aluminium with its alloy is one of the often-used materials caused its low density and good mechanical performances (Ricci *et al.*, 2017).

One of these inspection methods are eddy current (EC) which are involvement of electromagnetic induction phenomenon. In this EC testing have attention on excitation coils to produce primary field for worth it measurement, detecting devices to calculate the eddy current-induced field, known as secondary magnetic field using magnetic sensors or driver coils and the signal processing or character extraction for imperfection analyse or classification. Eddy current testing (ECT) also usually used for detecting imperfections such as fatigue cracks, inclusions, voids and holes in the conductive materials. By using a B-scan sweeping procedure, detection of small imperfection having the shape of an open hole is inspected throughout observing the variation response of the voltage in the receiver coils (Aoukili *et al.*, 2016).

The variation of the mutual distance between the exciting probe and material under testing cause to change the eddy currents dispersion inside the material and so a change of the signal received by the eddy current sensor (Ricci *et al.*, 2017). Thus, variations in the lift-off effects between the EC probe and surface of material testing has extremely affecting from errors on the obtained signals for either the voltage or magnetic field signal inspection (Tian *et al.*, 2006). Basically, through the analysis of the output signal of eddy current testing, the information about material feature, imperfections, lift-off distance and others could be obtained (Zhou *et al.*, 2015). A small variation of lift-off will result in large change in signal response which can be caused by varying coating thickness, irregular sample surface or movement of operators (Huang *et al.*, 2009).

Eddy current methods have been used in various technological applications such as quality inspection, coating and surface treatment (Yin *et al.*, 2007). Tian *et al.* (2006) designed the eddy-current testing probe with a new structure for scratch detection with high lift-off height by using the perpendicular exciting coil and a spin-valve-type giant magneto-resistance sensor (GMR). Researched by Zhou et al. (2015) based on the results simulation only studied the comparison of different type of probes with higher detection sensitivity of eddy current probe affects the performance of the system.

Based on previous research, Aoukili *et al.* (2016) investigated the surface crack detection in metallic parts through modelling the eddy current design induced by a variable magnetic field with only optimize the positions of the receiver coils.

Therefore, the output signal of different area or space of imperfection surface will be observed over the material testing which is aluminium flat bar by using an established eddy current testing (ECT) technique that included the excitation coil, the sensing or receiver coil, the tested imperfect material testing, ambient air and a simple circuit to measure the output signal of optimum lift-off for the specific eddy current design.

ANALYSIS OF EXPERIMENT

Based on an established of eddy current sensors with planar coil that have a maximum testing area of 2.25 cm^2 and an output impedance in the range of the entrance impedance of normal commercial instrument was 5 to 200 Ohm (Fava *et al.*, 2015). The principle of eddy current shown in Figure 1 and this inspection was used an established dual sensor consists of excitation coil and receiver coil to detect the output voltage of material testing installed by an artificial imperfection as shown in Figure 4. In execution of eddy current technique for detection of imperfection sets commonly on two circuits, the first one consists of the inductive part which is excited by a current pulse centred on a given work frequency to generate variable magnetic field in the test material. The second circuit takes the form of a coil sensor (Aoukili & Khamlichi, 2018). In addition, an amplifier used a specific op-amp to boost up the voltage of the alternate current (AC) source and the circuit is efficient used with different range of desired frequencies to obtain the signal response varied by variation of lift-off values.

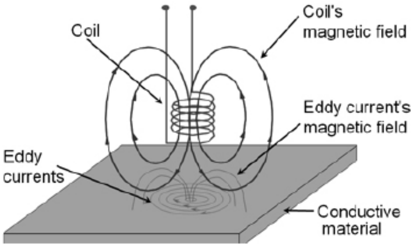

Figure 1. The principle of eddy current testing (Kim, 2016).

Dual Sensors

Healthy Dual sensors mean that used a probe consists of excitation coils and receiver coils which are located together as geometry shown in Figure 2. In this case, a parametric probe of an encircling type or circular planar coil was used and this sensor coils are made from copper wire. The probe presents an excitation coil with 100 turns of windings, 10 mm of height, inner diameter was 20 mm and outer diameter was 22 mm and the receiver coil with 80 turns of windings, 5 mm of height, inner and outer diameters were 10 mm and 12 mm. The measurement was made at fixed frequencies range from 250 kHz to 3.5 MHz. Where σ denotes as the conductivity of material testing, μ denotes as the permeability of material testing, N denotes as the number of turns in the receiver coil, n denotes as the number of turns in the excitation coil, D denotes as the diameter of the receiver coil, d denotes as the diameter of the excitation coil, while h and H denote as the height of the bottom and top of the coil and c denotes as the thickness of the flat bar.

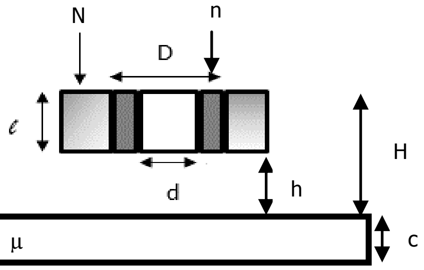

Figure 2. The geometry of the coil.

Material Testing

In this inspection involve of material tested was aluminium flat bar as shown at Figure 3, for its dimension sizes. The material testing is made of FB6061 aluminium and pattern of rectangular flat bar with 300 mm in length, 38.10 mm in width and 6.35 mm in height. Based on the International Annealed Copper Standard (IACS) was 42% of conductivity and the permeability was 1.

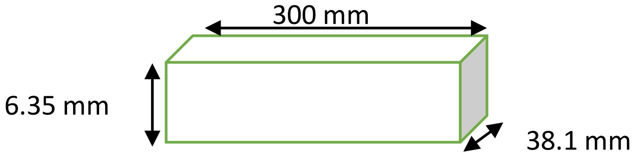

Figure 3. Dimension sizes of aluminium flat bar.

Imperfection Area

Area of imperfections on the testing material as shown in Figure 4 were inspected using an artificial imperfection with different dimensions. Figure 4 shows the geometry side of imperfection surface on the testing material which are different in height or depth (i.e., 1 mm, 3 mm and 5 mm) and same with the size of diameter which was 2 mm. These differences of geometry side or surface areas of imperfections (i.e., 2.326 cm^2, 3.930 cm^2 and 5.534 cm^2) were used for inspection on the output signal related to the imperfection detection.

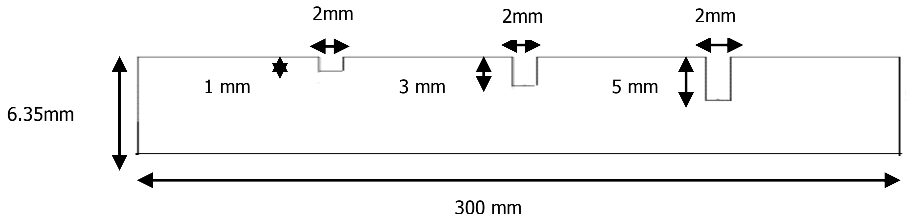

Figure 4. The geometry of imperfection surface on the aluminium flat bar.

RESULT

Eddy Current Testing on Aluminium Imperfection

In this investigation, aluminium flat bar (FB6061) was selected as material testing in detecting metal imperfection. The material testing with three (3) different kinds of surface imperfection were used for inspection with the high of excitation frequencies around 250 kHz to 3.5 MHz but then fixed ranging from 2.65 MHz to 2.95 MHz regarding to the obvious or optimum range in presenting the result of imperfection detection. Then the output voltage signals based on the different imperfection surface were plotted in a graph to compare the differences finding in imperfection detection. Figure 5 shown at frequency 2.65 MHz, the voltage(V) outputs which are the gradient of the imperfection surface was increased for LO-0, LO-1, LO-2, and LO-3. However, the voltage (V) outputs decreased for LO-4 and LO-5. Figure 6 shown at frequency 2.75 MHz, the gradient of the imperfection surface was increased at lift-off values for 1 mm (LO-1) and decreased gradient line of lift-off values from 2 mm (LO-2) to 5 mm (LO-5). Besides, Figure 7 and Figure 8 shown at frequency 2.85 MHz and 2.95 MHz, both have the gradient line of the imperfection surface was increased of lift-off values at 0 mm only which mean increased the output voltage signal as increased the area of imperfection surfaces without the presence of lift-off distance.

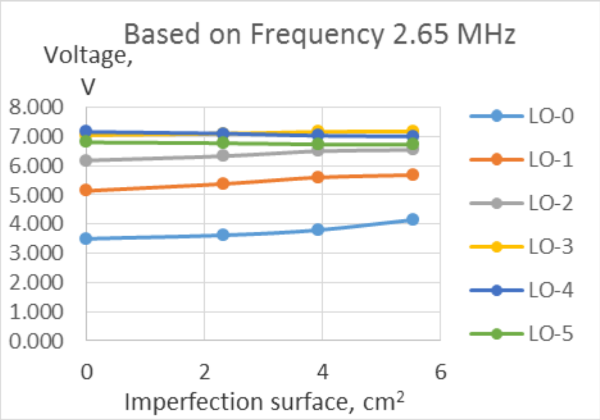

Figure 5. The graph of imperfection versus attribute voltage based on frequency 2.65 MHz.

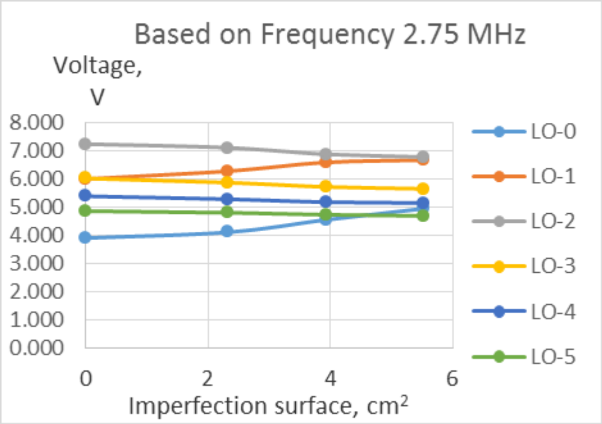

Figure 6. The graph of imperfection versus attribute voltage based on frequency 2.75 MHz.

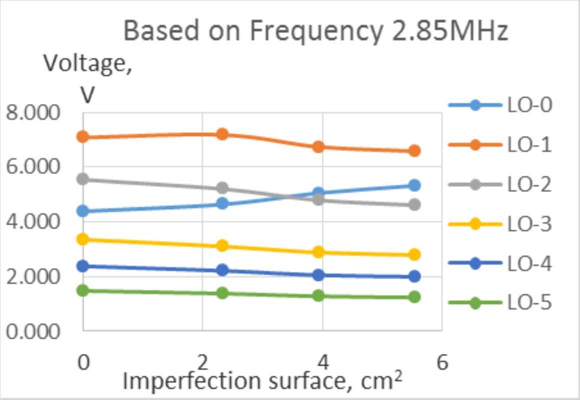

Figure 7. The graph of imperfection versus attribute voltage based on frequency 2.85 MHz.

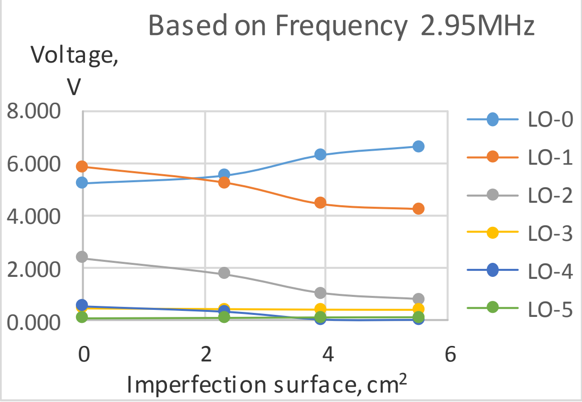

Figure 8. The graph of imperfection versus attribute voltage based on frequency 2.95 MHz.

Optimum Lift-Off Eddy Current Testing

Figure 9 shows the amplitude of output voltage was higher as increased the lift-off values. The detection of imperfection for the different sizes were indicated the signal responses which is optimum lift-off value achieved was around 3 mm but in term of detection imperfection shown that the obvious differences at lift-off value 2 mm. The sizes of imperfection were divided with three kind of types which are same the size of width but different size of depth such as for imperfection 1 was 1 mm (2.326 cm^2), imperfection 2 was 3 mm (3.930 cm^2) and imperfection 3 was 5 mm (5.534 cm^2) respectively. Besides that, Figure 10 shown that the signal response of output voltage becomes lower as the lift-off values was increased from 3 mm to 5 mm. The optimum lift-off value obtained at frequency 2.75 MHz was 2mm but for indicated the obvious responses in imperfection detection for three different kinds of imperfection sizes considered at lift-off value was 1 mm. The Figure 11 shown that the signal response of output voltage becomes lower as the lift-off values was increased from 2 mm to 5 mm. The optimum lift-off value obtained at frequency of 2.85MHz was 1mm but only indicated the obvious responses in detection of imperfection size for 1 mm of depth (imperfection size 1). Whilst, the Figure 12 shown that the signal response of output voltage becomes much lower as the lift-off values was increased where is at the frequency for 2.95 MHz indicated the obvious responses in detection of imperfection size only when no presence of lift-off value.

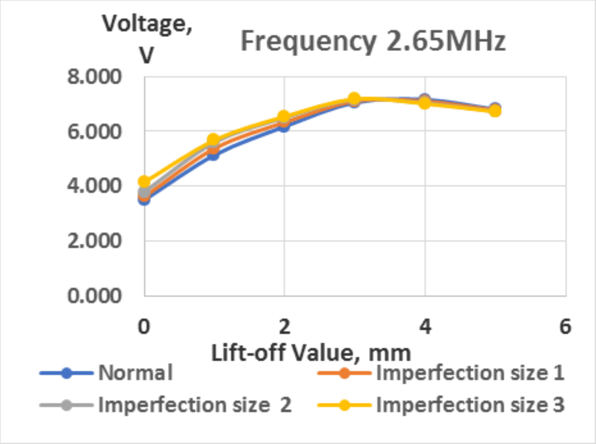

Figure 9. The graph of lift-off values in detection of different imperfection sizes based on frequency 2.65 MHz

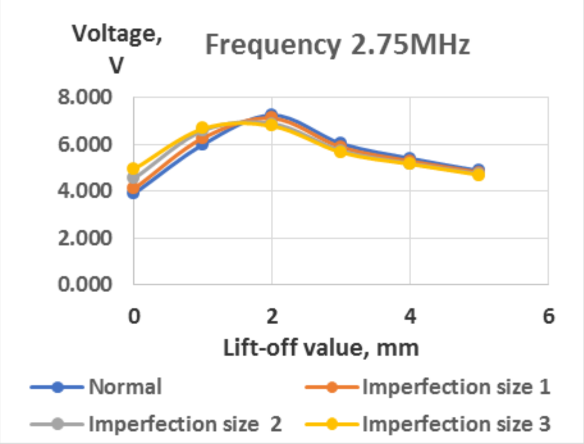

Figure 10. The graph of lift-off values in detection of different imperfection sizes based on frequency 2.75 MHz

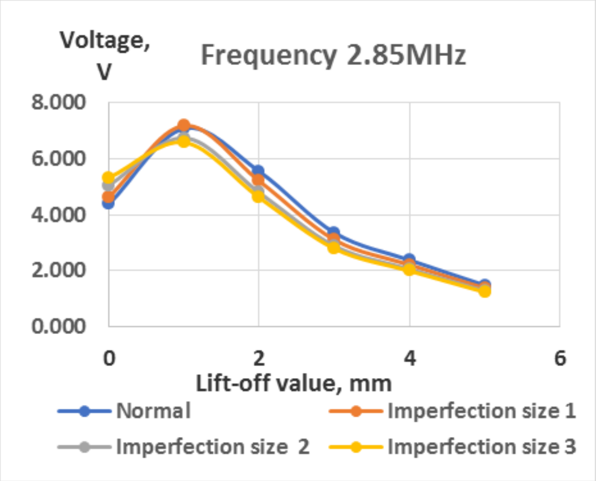

Figure 11. The graph of lift-off values in detection of different imperfection sizes based on frequency 2.85 MHz

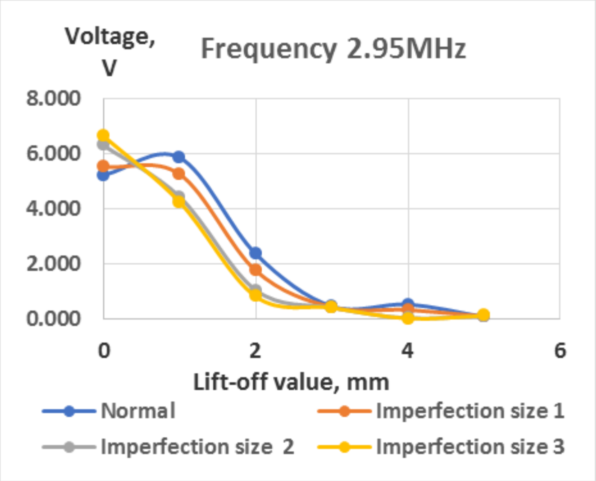

Figure 12. The graph of lift-off values in detection of different imperfection sizes based on frequency 2.95 MHz

DISCUSSION

Based on the results obtained, it is concluded that the magnitude value or attribute output voltage of EC increases with increasing the frequency but not in the responses of the imperfections detection. The graph illustrated in Figure 8 shown that at higher of lift-off value, induced eddy currents generated was reduced caused by the secondary magnetic field produced by induced eddy currents also was weaken so that detected prior magnetic signals from the imperfections become weak more. Furthermore, as the test coil was placed in a high lift-off position, the distance between the test coil and surface of a detected material testing was tended to make the secondary magnetic signals disturb from critical reduced again (Tian *et al*., 2006). Other than that, Zhou *et al.* (2015) was designed a new type of probe with studied the imperfection's width, length and depth. Hence, from the result of imperfection detection shown that the larger signal responses of output voltages as increased of dimension of imperfection size. At the frequency 2.65 MHz shown the proper results in detection of imperfections when the lift off value obtained was at 2 mm. As prior research Huang *et al*. (2009) acquired the suitable lift-off value was around 2mm for the specific electromagnetic acoustic transducer (EMAT) system with considering both sensitivity and stability of the transducer. When the lift-off value was higher than 3mm obtained the values for the output voltage of imperfection detection in different range were small but still could be considered, the noise level overrun the amplitude of the signal caused the signal response was weakened. Based on research Deng *et al.* (2018) the variation of lift-off affects or various of distance between the surface of the material testing and the detection coils caused the changes the degree of the coupling between the coil and material testing that lead to the impedance change of the coil. Therefore, the amplitude of output voltage reduces to a small value which is difficult for test coil sensors to detect. Whilst, at the frequencies range 2.75 MHz and 2.85 MHz shown that the obvious signal response for the measuring lift-off values but slowly decreased the efficiency in detection of imperfection, where the optimum lift-off value achieved was at 1 mm. Lastly, at frequency 2.95 MHz shown that obvious detection imperfection when no presence of the lift-off value but at certain intersection point of lift-off value was 3mm shown the detection for all of the imperfections obtained the almost similar of output voltage. Therefore, based on the research Tian *et al.* (2006) was designed the technique of dual frequency eddy current non-destructive testing conclude that for measuring the lift-off was used the higher frequency excitation, whilst for imperfection detection and sizing was used the lower frequency excitation.

CONCLUSION

In this paper, the eddy current (EC) probe which is a circular planar coil based on magnetic or B-scan inspection procedure was used to produced and sense the electrical current or attribute voltage in detection of imperfection for metallic part or material testing to applicable the various lift-off value that suitable of the specific eddy current design. From the result shown that the applicable lift-off values were 3 mm for 2.65 MHz, 2 mm for 2.75 MHz, 1 mm for 2.85 MHz and 0 mm for 2.95 MHz as were tested for this specific design of eddy current testing technique. Therefore, conclude that at certain frequencies such as lower frequency shown that signal response could be focused on the imperfection detection and at the higher frequency shown that signal responses for measuring the lift-off value as decreased of the efficiency of the imperfection detection on the testing material. This result obtained were influenced by many factors such as condition of handling the experimental tools and the surrounding that could be contribute to differences of previous research.

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