OPTIMUM DISTANCE OF LIFT-OFF HEIGHT TO DETECT DEFECT ON TESTING MATERIALS USING EDDY CURRENT TESTING TECHNIQUE

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ABSTRACT

Eddy Current Testing (ECT) technique is one of the Non-Destructive Testing (NDT) methods that is sensitive to the unintended signal such as the lift-off (LO) effect. For ECT technique, LO effect is one of the constraints due to the weakened detection that affected the output of the signals. This presented research aims to develop a coil probe that generates eddy current signals by using an ECT technique to determine the optimum distance of LO height for three different chosen materials (e.g., copper, brass, and magnesium alloy) of three (3) different thickness which is 1.5 mm, 3.0 mm and 5.0 mm each. The output voltage of the defects signal of the tested materials can be determined from the optimum distance of LO height of the ECT technique. The coil probe used consists of an exciter-receiver coil, where 5.25 MHz is the optimal frequency. This frequency then generates the signal of the ECT technique. This technique was set up using a 50 ohms function generator and an established amplifier to boost up the output signals. The acquired optimum distance LO height for this research is approximately 2 mm. The findings from this established technique indicate that the determined LO height can be determined from the output voltage signal of the defects as well as to detect the thicknesses. The output voltage signal from the ECT technique was analysed and compared. As conclusion, the output voltage signals slightly increased for larger material defects and subsequently decreased with greater thickness detection. Hence, the LO height parameters of the ECT technique in this research can detect defect appropriately.

ABSTRAK

JARAK OPTIMUM BAGI KETINGGIAN JARAK ANGKAT UNTUK MENGESAN KECACATAN PADA BAHAN UJIAN MENGGUNAKAN TEKNIK UJIAN ARUS PUSAR

Teknik uijan arus pusar adalah salah satu kaedah ujian tanpa musnah yang sensitif terhadap isyarat yang tidak diingini seperti kesan jarak angkat. Untuk Teknik ECT, kesan LO adalah salah satu kekangan kerana pengesanan yang lemah mempengaruhi isyarat keluaran. Penyelidikan yang dibentangkan ini bertujuan untuk mengembangkan gegelung yang menghasilkan isyarat arus pusar menggunakan teknik ECT untuk menentukan jarak optimum ketinggian LO untuk tiga bahan terpilih yang berbeza (contohnya, kuprum, tembaga, dan aloi magnesium) dari tiga (3) ketebalan berbeza yang masing-masing berukuran 1.5 mm, 3.0 mm dan 5.0 mm. Voltan keluaran isyarat kecacatan bahan yang diuji dapat ditentukan dari jarak optimum ketinggian LO bagi Teknik ECT. Siasatan gegelung yang digunakan terdiri daripada gegelung penerima-pengujaan, di mana 5.25 MHz adalah frekuensi optimum. Kekerapan ini kemudian menghasilkan isyarat teknik ECT. Teknik ini disusun menggunakan fungsi penjana 50 ohms dan penguat yang mapan untuk meningkatkan isyarat keluaran. Tinggi jarak optimum LO yang diperoleh untuk penyelidikan ini adalah sekitar 2 mm. Penemuan dari teknik ini menunjukkan bahawa ketinggian LO yang ditentukan dapat ditentukan dari isyarat voltan keluaran kecacatan dan juga untuk mengesan ketebalannya. Isyarat voltan keluaran dari teknik ECT dianalisis dan dibandingkan. Sebagai kesimpulan, isyarat voltan keluaran sedikit meningkat untuk kecacatan bahan yang lebih besar dan seterusnya menurun dengan pengesanan ketebalan yang lebih besar. Oleh itu, parameter ketinggian LO Teknik ECT dalam penyelidikan ini dapat mengesan kecacatan dengan tepat.

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LIST OF ABBREVIATIONS

AC - Alternating Current
BHP - Bolt Hole Probes
Cu - Copper
DC - Direct Current
DPI - Dye Penetrant Inspection
EC - Eddy Current
ECT - Eddy Current Testing
EMAT - Electromagnetic Acoustic Transducer
EMF - Electromotive Force
E-NDT - Electromagnetic Non-Destructive Testing
GMR - Giant Magneto Resistors
IACS - International Annealed Copper Standard
IC - Integrated Circuit
ID - Inside Diameter
LO - Lift-Off
MFL - Magnetic Flux Leakage
Mg - Magnesium
NDE - Non-Destructive Examination
NDE - Non-Destructive Evaluation
NDI - Non-Destructive Inspection
NDT - Non-Destructive Testing
OD - Outside Diameter
Op-amp - Operational Amplifier
SQUIDs - Superconducting Quantum Interference Devices
SNR - Signal Noise Ratio
UFEC - Uniform Field Eddy Current

LIST OF SYMBOLS

δ - Skin depth
μ_o - Magnetic permeability of free space
ω - Angular frequency
σ - Conductivity
π - Pie
cm - Centimetre
f - Frequency
kV - Kilo volt
kHz - Kilohertz
L - Inductance
MHz - Megahertz
mA - Milliammeter
mm - Millimetre
msec - Millisecond
V - Volt
v - Amplitude
X_L - Inductance coil
I - Electric current
R - Resistance
V_L - Induced voltage
dQ/dt - Rate of change of magnetic flux
di/dt - Rate of change of current
N - number of turns
D - Diameter
h - Height
H - Henries
K - Dimensionless constant
μ_r - Relative magnetic permeability
r - Radius
j - Imaginary unit
ε - Dielectric constant
A - Magnetic vector potential

J_e - Excitation current intensity
B - Magnetic flux density
C - Capacitance
β - Beta
Z - Impedance
Φ - Phase angle
t - Time
c - Thickness

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CHAPTER 1

INTRODUCTION

1.1 Introduction

This chapter outlines a brief introduction to the non-destructive testing related to the study of lift-off in eddy current testing techniques and an overview of the work implementation. Additionally, this chapter explained the aims, objectives, existing problems, and the research design of this research. Henceforth, this chapter also describes the scope of research and some of the operational meaning for this research. Lastly, the organization of the thesis content was discussed.

1.2 Research Background

One of the crucial parts of the detection defect in the industry was related to the condition surface or subsurface of certain materials (Yin and Peyton, 2007). Occasionally it is imperative to implement a technique for defect detection in a materials component by testing the probe at specified Lift-Off (LO) height, LO is the vertical distance between the base of the probe and the material surface (Wen *et al.,* 2018). Since a small variation of lift-off will result in a large change in signal response that will influence on the received signals for either the voltage or magnetic field signal measurements, therefore in this research work is intent to looking for alternatives to minimize these influences (Huang *et al.,* 2009; Tian *et al.,* 2009).

Defect detection in material characterization with the optimum distance of LO height in Eddy Current Testing (ECT) has wide and important applications to a variety of magnetic and non-magnetic conducting material (Desjardins *et al.,* 2016). For instance, to measure a non-conductive multilayer, an irregular or uneven roughness surface, and welding testing embedded material without dismantling operation (Wen *et al.,* 2018). Other than that, this could be applied for fuselage skin painted, varnished materials, and material composite laminated (Wang *et al.,* 2018). Furthermore, the LO height was applied to prevent the probe from high-temperature damage in the heat treatment status while inspecting the material (Li *et al.,* 2015; Tian *et al.,* 2006). Also, a study by Egorov *et al.* (2015) states the distance between the probe and the surface of the test material is under control for overhead of the probes.

The LO is known as one of the constraint parts in the eddy current testing system due to weakened detection responsiveness that affects the performance of the signals (Wen *et al.,* 2018). In the case of a high LO height, the received signal will be attenuated rapidly with increasing LO value. If the adoption is very large, the results detected by the probe will be very weak to be recognized. As a result, the secondary magnetic field produced by attenuated eddy currents is also weakened so that the detected magnetic signals from defects become weaker. Moreover, as the probe is in a high LO position, the distance between the probe and surface of a detected material tends to make the secondary magnetic signals suffer from acute attenuation again (Ding *et al.,* 2012). Therefore, most of the detection made by ECT detections is done in intimate contact with the material being tested or at low LO because it is a complicated detection in high LO (Tian *et al.,* 2006).

Therefore, to increase the signal responses, the coil probe for the ECT technique needs to be built to affect the area of the coil cross-section and to cover the magnetic flux density (Yan *et al.*, 2017). One of the critical parameters to increase the signals response is related to the continuous sine wave of an operating frequency used to penetrate the testing material due to the skin effect that is influenced by the use of eddy current coil (Tian and Sophian, 2005). In the case of material characterization, the election of various materials will be tested for an indication signal of the coil probe (Egorov *et al.*, 2015; Yan *et al.,* 2017). It has been signalized that different type of materials has a different value in electrical conductivity, σ, and magnetic permeability, μ as influence the changing signal obtained due to structural, hardness and internal stress in the material, for example, copper and brass which are considered causing the minimal testing for an optimum distance of LO height. The testing also needs more various types of materials characterization using the ECT technique so that they discover that LO may have advantages in detection for any kinds of that problematic surface condition of the certain materials (Blitz *et al.,* 1987).

Whilst, the optimum distance of lift-off height is one of important parameters for ECT techniques that has the potential to improve the accuracy of the defect detection in structural components, also take specific demands on developing the appropriate technique that facilitates a researcher's understanding through the finding research. Besides, to help or guide another researcher by using the reference data obtained, the researcher needs to study further on how to expand the ECT technique within a constructivist model consistent with the objectives of the Non-Destructive Testing (NDT) industry. Furthermore, this technology is concerned about how to ensure and assure quality control, standardize the quality testing and material testing so it is continuously safe to use.

1.3 Application Study of Lift-off Height

This technology of the Eddy Current Testing (ECT) technique is used to ensure quality control for testing according to the standards and to be safe to use continuously. ECT used a non-contact detection on the defect surface but due to the work the effect of disturbance from errors of variations in the distance between the coil probe and test material, known as Lift-Off (LO) height caused by uneven surface roughness whenever the eddy current detection is difficult to analyse the originality of the actual defect signal (Gutierrez, 2017). In recent years, research about the LO effect has been focused on whether in the field of coil probe design, a signal from the perspective of rationality and detection strategy, this variety of testing technique is designed to improve the detection accuracy. A critical part of the LO height was the use of an operating frequency to acquire the promising result in defect detection on material testing.

Several studies regarding the use of frequency for LO height, for instance, He and Yoshizawa (2002) develop a dual-frequency eddy current system based on superconducting quantum interference devices in the detection of defects by choosing appropriate excitation frequencies but using this development to reduce the variance of LO height. In other research by Alias *et al.,* (2018), a design of the eddy current method by using the sine wave oscillator circuit and sensor circuit to acquire an optimal frequency for the testing material instrument. However, this research aim is only to find the optimal frequency of defect detection without emphasizing the signal output of the LO height.

Another study by Mandache and Lefebvre (2006) where the configuration of a testing technique using LO intersection point is defined by the discrete harmonic content of the initial pulse representation of the Fourier series. This design results in a signal response that is varied by the LO height but less sensitive to the detection of defects using an absolute coil or a single-coil probe. Besides, research by Ko *et al.* (2008) also designs the eddy current calculation using the LO curve and the cable connecting to a network analyser and a traditional eddy current probe instead of improving the configuration of the coil probe to track the surface conditions due to the shot peening. However, this design-focused solely on measuring the property of the material and detecting the state of the surface material being tested, which was less concerned with detecting defect signals. Another study by Ricci *et al.* (2017) with the use of a magnetic field sensor (GMR sensor) is to evaluate amplitude and phase signals under multi-frequency current excitation, which enables the comparison of different strategies in terms of image quality to reveal the defect even in the presence of massive LO shifts.

Therefore, this research was implemented to find the output voltage signals for material processing using a coil probe (receiver and excitation coil). By setting higher operating frequency with an established amplifier instrument to boost up the output voltage signals of the optimum distance of LO height used to detect on the test materials by using the ECT technique.

1.4 Problem Statement

Non-Destructive Testing (NDT) is now facing a new challenge for a defect detection and job growth in the quality control of advanced engineering materials or equipment that need development and manufactured in quality so that it would improve continuously (Berger *et al.,* 2017). The failures of engineering materials, modules and systems are well known. They can be catastrophic due to avoid cost-effectively while maintaining the quality of use and reliability of a wide range of industrial products (Kahrobaee *et al.,* 2018; Almeida *et al.,* 2013). Hence, one of the NDT methods is Eddy Current Testing (ECT) technique, which needs to improve the performance of the technique due to the lower detection accuracy and the surface condition of the test material, the change in the distribution of eddy currents within the material including geometric parameters. The technology of ECT techniques which are trusted to be possibly rich in information that reactive to the unintended signal such as Lift-Off (LO) height (Tian and Sophian, 2005).

The LO parameter is defined as the distance between a probe and the material under test. A small change in LO variation can cause the abrupt change in signal response. Until now, research on how to reduce the impact of LO signal remains a problem even for today's advanced eddy current instrumentation (Fan *et al.,* 2015). Whilst there are a few researchers are aware that the study on higher LO height could provide additional significant information on the testing system. The main factor related to this problem is the movement of the probe in inspection and the surface of the materials influences the acquired signals which are related to electromagnetic characteristics. In this research, various tested materials were used to acquire more information on defects. A uniform LO height is preferred for achieving a better detection sensitivity to defects and for fast, reliable sensing (Zhou *et al.,* 2015). Throughout this research with finding the optimum distance of LO height of ECT shows that limitation of the response signal of the specific technical design that could be referred for further development of methods.