DEVELOPMENT OF EDDY CURRENT TESTING INSTRUMENT ON METAL TESTING FOR NON-DESTRUCTIVE TESTING APPLICATIONS

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ABSTRACT

Eddy current facilities are rapidly developing in the field of industry and the effectiveness of the eddy current testing (ECT) instrument is well established on market and yet, the instruments were very expensive and hard to get in this country. Moreover, the optimization for the specification of metals testing is still lacking in research and development. The alternative approach as discussed in this research is by design and construct a low-cost non-destructive metal testing instrument using eddy current method that able to examine the signal imperfection, detect thickness (1.5, 3.0 and 5.0 mm) and lift-off distance (1.0-5.0 mm). The frequency ranges between 250 kHz-3.5 MHz by using 50 ohms function generator is selected to find the optimal frequency for each metal testing (i.e., Brass, Cu, Mg Alloy, Ni and Ti). The important part in constructing the ECT instrument is the dual coil sensor which is known as exciter-receiver coil designed in appropriate turns of coils and the instrument amplifier that give a high output voltage that excel at extracting very weak signals from noisy environments. The output voltage signals from the sensor circuit of the ECT instrument were analyzed and compared. The result of this research showed that the designed ECT instrument able to examine the signal imperfection and also to detect the thickness. The lift-off distance for the ECT instrument is at 1 mm. Meanwhile, the optimal frequency on each metal for the ECT instrument is at 2.90 MHz for Brass, 2.95 MHz for Copper, 2.89 MHz for Magnesium Alloy, 2.85 MHz for Nickel and 2.83 MHz for Titanium. The ECT instrument that is developed from this study can efficiently generate an accurate output reading and suitable for industrial application requirements.

Keywords: NDT, eddy current testing, optimal frequency, testing instrument.

ABSTRAK

MEREKABENTUK INSTRUMEN UJIAN ARUS PUSAR KE ATAS LOGAM DENGAN APLIKASI UJIAN TANPA MUSNAH

Kemudahan arus pusar kini berkembang pesat dalam bidang industri dan keberkesanan instrumen ujian arus pusar sudah mantap di pasaran tetapi instrumen ini sangat mahal dan sukar diperoleh di negara ini. Selain itu, pengoptimuman spesifikasi ujian logam masih kurang dalam penyelidikan dan pembangunan. Pendekatan alternatif seperti yang dibincangkan dalam kajian ini adalah dengan merekabentuk dan membina instrumen kos rendah dengan menggunakan kaedah arus pusar dengan ujian tanpa musnah yang dapat menguji ketidaksempurnaan logam, pengesanan ketebalan logam (1.5, 3.0 dan 5.0mm) dan jarak angkat yang sesuai bagi instrumen (1.0-5.0mm). Kekerapan antara 250 kHz-3.5MHz dengan menggunakan 50 ohms fungsi penjana dipilih untuk mencari frekuensi optimum untuk setiap ujian logam (iaitu, Brass, Tembaga, Aloi Magnesium, Nikel dan Titanium). Bahagian penting dalam membina instrumen ECT ialah dwi-pengesan yang dikenali sebagai gegelung penerima-pengujaan yang direka dalam lilitan gegelung yang sesuai dan penguat instrumen yang memberikan voltan keluaran yang tinggi untuk mengeluarkan isyarat yang sangat lemah daripada persekitaran yang bising. Isyarat voltan keluaran dari litar pengesan instrumen ECT dianalisis dan dibandingkan. Hasil daripada kajian ini menunjukkan instrumen ECT yang direka untuk menilai ketidaksempurnaan logam dan ketebalan pengesanan. Jarak angkat untuk instrumen ECT berada pada 1mm. Sementara itu, frekuensi optimum pada setiap logam untuk instrumen ECT adalah pada 2.90MHz untuk Brass, 2.95MHz untuk Tembaga, 2.89MHz untuk Aloi Magnesium, 2.85MHz untuk Nikel dan 2.83MHz untuk Titanium. Dengan cara ini akhirnya, instrumen ECT dapat menghasilkan bacaan yang tepat dan sesuai untuk keperluan aplikasi perindustrian.

Kata kunci: NDT, ujian semasa eddy, kekerapan pengoptimuman, alat ujian.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

Cu	-	Copper
CMRR	-	Common-Mode Rejection Ratio
ECT	-	Eddy Current Testing
EMF	-	Electromagnetic force
$FeCl_3$	-	Ferric Chloride
IACS	-	International Annealed Copper Standard
IC	-	Integrated Circuit
Mg	-	Magnesium
NDT	-	Non-destructive testing
Ni	-	Nickel
PCB	-	Printed Circuit Board
Ti	-	Titanium
UT	-	Ultrasonic Testing

LIST OF SYMBOLS

±	-	Plus minus
+	-	Plus
-	-	Minus
%	-	Percent
δ	-	Skin depth
μ_o	-	Magnetic permeability
ω	-	Excitation frequency
σ	-	Conductivity
π	-	Pie
AC	-	Alternating Current
cm	-	Centimeter
DC	-	Direct current
f	-	Frequency
kg	-	Kilogram
kV	-	Kilo volt
kHz	-	Kilohertz
L	-	Inductance
MHz	-	Megahertz
mA	-	Miliammeter
mm	-	Milimeter
msec	-	Millisecond
V	-	Volt
v	-	Amplitude
XL	-	Inductance coil

LIST OF APPENDIX

CHAPTER 1

INTRODUCTION

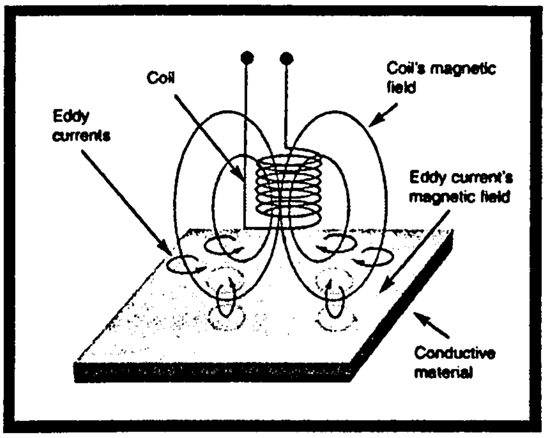
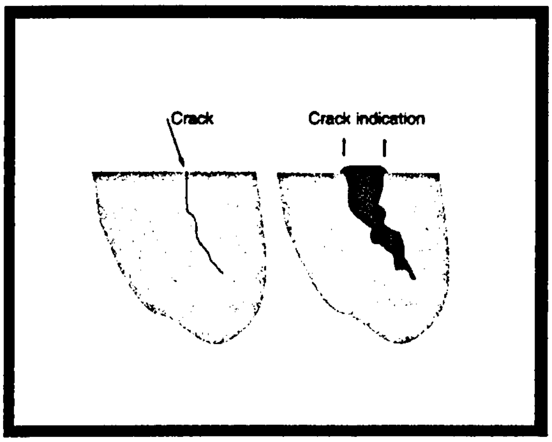
1.1 Research Background

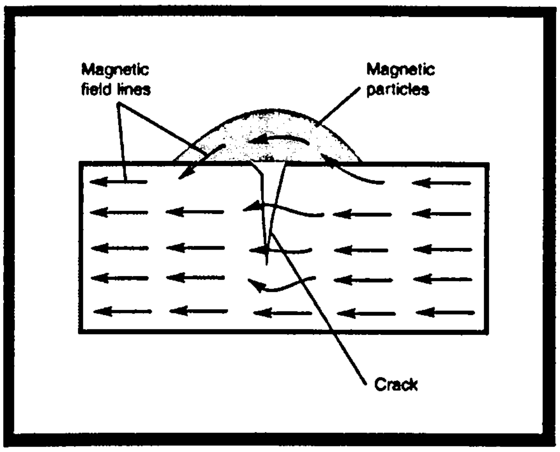
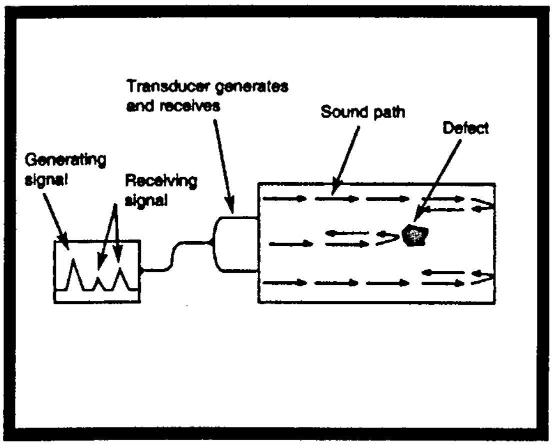
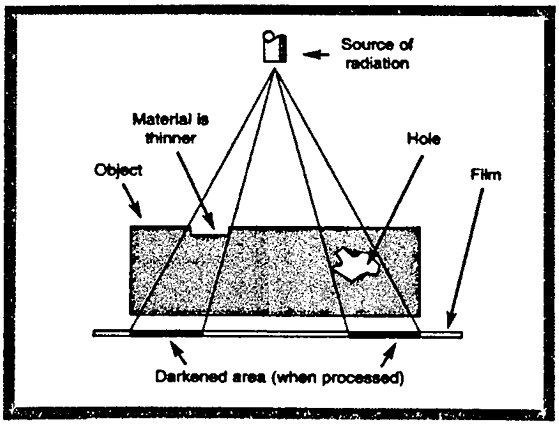
Non-destructive Testing (NDT) is a wide group of analysis techniques used in the science and technology industry that use the non-invasive techniques to determine the integrity of a material, component, structure or quantitatively measure some characteristics of an object (Kumar & Mahto, 2013). It is made up of the techniques that are based on the application of physical principles employed to determine the characteristics of materials and for detecting and assessing the flaws and harmful defects without any change in their usefulness or serviceability (Li, 2012).

NDT is a highly valuable technique in ensuring cost-effective operation, the safety of use and reliability of a wide range of industrial and research departments (Simm, 2013). There are many reasons that industries are applying NDT methods for inspection purposes including providing better quality of products, reducing costs and increasing production detection of unwanted failures in the very beginning phase, providing the ability to inspect the equipment in operational state, reaching to higher levels of reliability and avoiding or reducing downtime and wastage of material (Zahirian, 2011). NDT provides a better understanding of flaws and defects existing in the equipment by clarifying the type, size, position and orientation of defects.

There is a broad range of NDT methods based on different physical principles but the most commonly used are eddy currents evaluation, ultra-sonic, X-radiography, magnetic particle inspection and dye penetrant application (Simm, 2013). Therefore, choosing a suitable method or a combination of several methods makes a big impact on the final results for a specific application. Table 1.1 shows the NDT method that most commonly used.

Table 1.1: Non-destructive testing methods

Methods	Diagrams
1) Eddy Current -Measures or detects surface and subsurface cracks of conductive material, heat treatment variations, wall and coating thickness, crack depth, conductivity and permeability.	
2) Liquid Penetrant Measures or detects defects open to the surface of parts such as cracks, porosity, seams, laps and through wall leaks.	

3) Magnetic Particle Measures or detects surface and qualified subsurface defects, cracks, seams, porosity, inclusions, and very sensitive for locating small tight cracks.	
4) Ultrasonic Measures thickness, velocity or detects internal defects and variations, such as cracks, lack of fusion and lack of bond. Applications include many material metal and non-metals.	
5) Radiography Measures or detects, internal defects and variations, porosity, inclusions, cracks, lack of fusion, corrosion, geometry variation, density changes, misassembled and misaligned parts. the part.	

Source: NDE Resource Center.net.

Eddy current testing (ECT) is one of the oldest and most popular non-destructive testing (NDT) methods due to its testing speed, reliability and low cost (Rosado *et al.*, 2014). Eddy currents evaluation or testing is the preferred NDT method for superficial and internal flaw detection on conducting materials, especially on metal applications.

Surface inspection and tubing inspection are two major applications of ECT. Surface inspection is used extensively in the aerospace industry and it is very sensitive and can detect cracks. This technique can be performed both on ferromagnetic and non-ferromagnetic materials (Xu, 2014). Tubing inspection is generally limited to non-ferromagnetic tubing. This technique is used for inspecting steam generator tubing in nuclear plants and heat exchangers tubing in the power and petrochemical industries (Shaikh, 2006).

According to Arjun *et al.* (2014), the heart of eddy current testing measurements is the probe. These come in a wide variety of configurations and sizes, but the fundamental principle of operation is the same for all. majority of eddy current instruments use a continuous sine wave of one fixed frequency as the drive for the eddy current coil (Liu et al., 2017). Other than that, the ECT instrument also uses the swept frequency method. This method is the same as the fixed frequency except that the frequency is no longer fixed but swept over a range of frequencies producing eddy currents ranging from low frequencies, which penetrate deeply into the material, to the high frequencies which induce eddy currents near to the surface only (Bouloudenine *et al.*, 2014). This results in more information which can be used to characterize the size and location of the flaw.

1.2 Problem Statement

Industrial development in Malaysia is fast developing nowadays. To be able to stand together with other countries, Malaysia needs to control its production standards and reliability. Malaysia is one of the users of the ECT method to ensure or assure quality control, to test the quality according to the standards and to keep maintenance. Eddy current testing method instrument has been commercial worldwide and widely used in industrial developments and yet, the instrument was very expensive and hardly available in this country. Some of the instrument were simulated and needed an expert to handle. Furthermore, if there is any technical problem or damages in the instrument it is hard to find suitable spare parts.

In research and development, ECT has been researched to improve the optimization of the coil probes, frequency ranges for the instruments, the lift-off effects and ECT in different material (Abrantes *et al.*, 2015; Cheng, 2017; Ulapane *et al.*, 2017; Angani *et al.*, 2015; Liu *et al.*, 2017). However, the optimization for the specification of metals testing is still lacking and not specified yet. According to Fan *et al.* (2016), optimal frequency plays an important role in defect characterization as well. At present, single frequency, multiple frequency and pulsed excitation are presented to acquire more information on defects. However, the influences of optimal frequency on defect characterization had not been paid much attention yet. Biju *et al.* (2009) stated that with optimal frequency will help to get accurate and fast result. Furthermore, NDT technicians are in high demand nowadays. The basis of inspection technology depends upon the technician's ability to understand the principles of physics and apply fundamental mathematical calculations to locate flaws and defects in materials.

Therefore, by creating a low-cost non-destructive metal testing instrument by using eddy current method without any simulation, that it is also effective in finding the optimal frequency for each specific metal, detecting metal defects measuring the metal thickness and lift-off distance that which improves the sensitivity and accuracy of the eddy current system. Furthermore, it also can help save costs for purchases from outside the country.

1.3 Research Objective

The objectives of this research are listed as follows:

1. Design and construct an eddy current testing (ECT) instrument which is highly affordable, provides real time monitoring and easy to handle.
2. Examine the signals imperfection, thickness detection with variation of metals (1.5, 3.0 and 5.0 mm) and lift-off distance for instrument in various distances (1-5 mm) from the ECT instrument.
3. Determine the optimal frequency between 250 kHz-3.5 MHz for each of metal testing (brass, copper, magnesium alloy, nickel and titanium) from the ECT instrument.

1.4 Research Design

The main purpose of this research is to construct an affordable, easy to handle, no simulation and providing instant results non-destructive metal testing instruments by using eddy current method. The optimal frequency for the several types of metals (Brass, Cu, Mg Alloy, Ni and Ti) will then be evaluated by using the ECT instrument.

In designing the metal testing instrument, the transmit-receiver sensor (dual-coil) needs to design and established first. It is widely known that in order to improve the sensitivity of the coil should have a large number of turns and a large active area (Tumanski, 2007). In order to make the design more accurate, the instrument amplifier was designed. Instrumentation amps excel at extracting very weak signals from noisy environments. Thus, they are often used in circuits that employ sensors that take measurements of physical parameters. This circuit would work faster and could be used with different range of frequency. A principle in design and practice was based on inverting type signal amplifier circuit.

The function generator is the most suitable tool in obtaining the optimization frequency. The function generator is a very versatile instrument as it can produce a wide variety of waveforms and frequencies. The function generator will be connected with the exciter coil with a frequency signal range between 250 kHz to 3.5 MHz. The pulsed excitation causes a rapid change in the surrounding magnetic field; this, in turn, induces eddy currents in the test piece being assessed. Finally, the digital millimeter will measure the output voltage signal for the testing metals.

1.5 Research Scope

To develop the eddy current testing (ECT) instrument, the first step is to design the excitation-receiver sensor and instrument amplifier based on theoretical and past research knowledge. In order to establish the well function ECT instrument design, three testing instruments will be tested which is metal imperfection; detection thickness with variation of metals and testing of lift-off distance. Another highlight of this research is to find the optimal frequency for each metal testing (copper, brass, magnesium alloy, nickel and titanium). Methods to determine the optimal frequency for metal testing are still the edge of knowledge and this work is a contribution to that area.

1.6 Thesis Arrangement

This thesis has been organized into five chapters. The first chapter briefly describes the background of Eddy Current Testing including their advantages, methods of production and principle process. The contributions of NDT in several sectors are also discussed in this chapter to signify the practicality of ECT and the significance of this research. The discussions that link between the motivation and the objectives of the studies are further highlighted to delineate the contribution of the thesis.

The second chapter is the literature review of the current study on Eddy Current Testing. The fundamental theory of the Eddy Current Testing is discussed in this section. For further understanding of ECT, the properties and the generation of ECT instrument methods are discussed. To provide a clear image of ECT instrument production, the revolutions of ECT from previous studies are also reviewed.

The third chapter discusses the detail of research methodology. Before the actual system development, the ECT instrument was designed and tested with several metals to obtain the best design in the development of the ECT instrument. Different parameters tested in the testing instrument process are discussed in detail in this chapter.

The fourth chapter would discuss all the findings from this research. The results for the ECT instrument in three kinds of test which is metal imperfection, detection thickness variation of metals and the suitable lift-off distance for the instrument. Other than that, the finding of optimal frequency for each of metal testing (Copper (Cu), Brass, Magnesium Alloy (Mg Alloy), Nickel (Ni) and Titanium (Ti)) would be discussed before the findings from the ECT instrument. The detail explanation is revealed part by part. The complementary discussion that relates the research finding of the thesis is all elaborated.

Finally, the fifth chapter is the conclusion of the important findings from this research. The recommendations for improvement in a similar field of study are also included.

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