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OPTIMISATION OF EDDY CURRENT THERMOGRAPHY FOR DEFECT DETECTION ON SELECTED STEEL SPECIMENS

NURLIYANA SHAMIMIE BT RUSLI

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By

NURLIYANA SHAMIMIE BT RUSLI

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science

May 2017

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DEDICATIONS

For my beloved parents,

RUSLI BIN MAT HUSSAIN

and

ZALINA BT ALI

And also to my siblings and family

To all my helpful lecturers and supervisors

To all my dearest friends.

With all your encouragement and support, a thesis on my research has been successfully completed.

May Allah bless all and ease everything.

Abstract of thesis presented to the senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Master of Science

OPTIMISATION OF EDDY CURRENT THERMOGRAPHY FOR DEFECT DETECTION ON SELECTED STEEL SPECIMENS

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NURLIYANA SHAMIMIE BT RUSLI

May 2017

Chairman : Professor Sidek b. Hj Ab Aziz, PhD
Faculty : Science

Eddy current thermography is one of the non-destructive testing techniques that provide advantages over other active thermography techniques in terms of defect detection and analysis. The method of defect detection in eddy current thermography has become reliable due to its mode of interactions, such as, eddy current heating and heat diffusion, acquired via an infrared camera. Such ability has given advantages for non-destructive testing applications. The experimental parameters and settings which contributed towards optimum heating and defect detection capability have always been the focus of research. In addition, the knowledge and understanding of the characteristics heat distribution surrounding a defect is an important factor for successful inspection results. Thus, the qualitative characterisation of defect by this technique appears to have advantages to the conventional non-destructive testing. This thesis focuses on the theoretical and experimental investigation, specifically in investigating the transient response and temperature distribution to the presence of defects. Signal to Noise Ratio (SNR) analysis is applied on the Austenitic Stainless Steel SS316 to identify the parameters which will prevail the most significant indication of defect by performing the optimisation parameter of heating time and excitation current applied. The outcome from the optimisation of SNR is beneficial to apply on the investigation of subsurface defect at area of HAZ, toe and root region. Numerical simulations of Comsol FEM Multiphysics concerning the visualisation of the resulting transient responses from eddy current due to the occurrence of the underlying phenomenon of eddy current interaction with defects was simulated. Angular defects of 0^0, 25^0 and 45^0 prevail that, greater angle of a defect will cause the amplitude of the linescan profile to become more slanted and a higher temperatureamplitude of the angle is acquired respectively. Furthermore, internal defect of different depths proves that the increase in depth of defects will cause the amplitude of the temperature profiles to decrease. The investigation for different sizes of defect stimulate a higher temperature at the surface of the specimen for the bigger

sizes of defect. The results of the experimental investigation is compared with the numerical simulation results to provide comprehensive verification towards the investigation.

Abstrak tesis yang dikemukakan kepada senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk Ijazah Master Sains

PENGOPTIMUMAN TEKNIK TERMOGRAFI ARUS PUSAR UNTUK MENGESAN KECACATAN PADA SAMPEL KELULI TERPILIH

Oleh

NURLIYANA SHAMIMIE BT RUSLI

Mei 2017

Pengerusi : Profesor Sidek b. Hj Ab Aziz, PhD
Fakulti : Sains

Termografi arus pusar adalah salah satu teknik ujian tanpa musnah yang mempunyai banyak kelebihan berbanding teknik termografi aktif yang lain bagi mengesan dan menganalisa sesuatu kecacatan. Teknik pengesanan kecacatan menggunakan termografi arus pusar telah menjadi satu teknik yang boleh diharapkan berdasarkan mod interaksinya, seperti, pemanasan arus pusar dan resapan haba yang diperoleh melalui penggunaan kamera inframerah. Keupayaan ini memberi kelebihan kepada teknik tersebut dalam aplikasi ujian tanpa musnah. Parameter dan aturan dalam eksperimen yang menyumbang kepada pemanasan yang optimum dan keupayaan pengesanan sesuatu kecacatan sentiasa menjadi tumpuan kepada penyelidikan yang berkaitan dengan teknik tersebut. Tambahan pula, pengetahuan dan pemahaman tentang ciri-ciri pengagihan haba di sekitar kecacatan adalah menjadi satu faktor penting untuk kejayaan mendapatkan keputusan pemeriksaan yang tepat. Oleh itu, pengujian kualitatif sesuatu kecacatan menggunakan teknik ini menunjukkan satu kelebihan berbanding dengan teknik ujian tanpa musnah yang konvensional. Tesis ini memberi tumpuan terhadap siasatan secara teori dan eksperimen, khususnya penyiasatan tentang kadaran gerak balas suhu dan taburan suhu terhadap pengesanan kecacatan. Analisis nisbah isyarat-hingar (SNR) diaplikasikan pada keluli tahan karat austenit SS316 untuk mengenal pasti parameter yang akan menunjukkan isyarat pengesanan kecacatan yang jelas dengan melaksanakan pengoptimuman bagi parameter yang melibatkan tempoh pemanasan dan arus pengujaan. Hasil dari pengoptimuman itu adalah sangat berfaedah untuk diaplikasikan terhadap pengujian kecacatan dalaman pada kawasan Zon Terkesan Haba (HAZ), tapak luar dan kawasan akar pada sampel karbon keluli yang dikimpal. Simulasi berangka 'Comsol FEM Multiphysics' yang melibatkan pembayangan gerak balas suhu yang terhasil disebalik fenomena interaksi arus pusar telah disimulasikan. Kecacatan bersudut pada 0^0, 25^0 dan 45^0 menunjukkan bahawa sudut kecacatan yang lebih besar akan menyebabkan amplitud imbasan profil garis menjadi lebih condong manakala amplitud suhu yang lebih tinggi daripada kecacatan bersudut akan diperoleh. Tambahan pula, ujikaji kecacatan pada kedalaman berbeza membuktikan bahawa peningkatan kedalaman

bagi sesuatu kecacatan akan menyebabkan penurunan amplitud profil suhu. Siasatan untuk pelbagai saiz kecacatan menunjukkan bahawa saiz kecacatan yang lebih besar menyebabkan suhu lebih tinggi pada permukaan spesimen. Keputusan dari ujikaji eksperimen ini dibandingkan dengan keputusan simulasi berangka untuk menghasilkan sesuatu pengesahan keputusan yang sangat komprehensif terhadap seluruh kajian yang dijalankan.

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I certify that a Thesis Examination Committee has met on 11 May 2017 to conduct the final examination of Nurliyana Shamimie bt Rusli on her thesis entitled "Optimisation of Eddy Current Thermography for Defect Detection on Selected Steel Specimens" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

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Associate Professor
Faculty of Science
Universiti Putra Malaysia
(Chairman)

Khamirul Amin bin Matori, PhD
Associate Professor
Faculty of Science
Universiti Putra Malaysia
(Internal Examiner)

Mohamad Deraman, PhD
Professor
Universiti Kebangsaan Malaysia
Malaysia
(External Examiner)

NOR AINI AB. SHUKOR, PhD
Professor and Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 6 July 2017

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfillment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

Sidek b. Hj Ab. Aziz, PhD
Professor
Faculty of Science
Universiti Putra Malaysia
(Chairman)

Zaidan b. Abd. Wahab, PhD
Associate Professor
Faculty of Science
Universiti Putra Malaysia
(Member)

Ilham Mukriz b. Zainal Abidin, PhD
Industrial Technology Division
Malaysian Nuclear Agency
(Member)

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ROBIAH BINTI YUNUS, PhD
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LIST OF ABBREVIATIONS

AC	Alternating Current
CFRP	Carbon Fiber Reinforced Plastic
DC	Direct Current
DIR	Digital Industrial Radiography
EC	Eddy Current
EM	Electromagnetic
ET	Eddy Current Testing
FEM	Finite Element Method
FOV	Field of View
FPA	Focal Plain Array
HAZ	Heat Affected Zone
IFOV	Instantaneous Field of View
IR	Infrared
MT	Magnetic Testing
NDT	Non-Destructive Testing
NETD	Noise Equivalent Temperature Difference
OD	Outer Diameter
PT	Penetrant Testing
RCF	Rolling Contact Fatigue
RT	Radiographic Testing
SNR	Signal to Noise Ratio
UT	Ultrasonic Testing
UV	Ultraviolet

CHAPTER 1

INTRODUCTION

1.1 Research Background

Over the last few decades, Non-Destructive Testing (NDT) has been widely used in industrial branches in order to indicate the presence of material discontinuities in metallic structures or components within the petrochemical, aerospace, nuclear, transportation and energy industries (Simm *et al*., 2010; Al-qubaa *et al*., 2011; Pan *et al*., 2012). There are several common methods of NDT such as Eddy Current Testing (ET), Penetrant Testing (PT), Ultrasonic Testing (UT), Magnetic Testing (MT) and Radiographic Testing (RT) (Yin *et al*., 2013; Brauer *et al*., 2014). Although NDT is now a relatively matured field, safety expectation increases along with the requirement for regular, low-cost inspections, and the ability to detect surface, sub-surface defects and defects with complex geometries.

Throughout this research, electromagnetic NDT of eddy current thermography has been applied. Recent trends of NDT is required for qualitative assessment of defect in the specimen being tested. It is indeed vital to monitor the safety of critical components. Therefore, numerical studies have helped the research of eddy current thermography testing technique for defect characterisation by predicting the results at a level comparable to experimental results. Thus, experimental results are used to validate the numerical studies. Numerical studies also involved 3D modelling and simulation which provide understanding of the underlying phenomena with respect to the interaction of the defects with eddy current (Wilson *et al*., 2010; Zhang *et al*., 2011). In addition, some conditions of the specimen geometry were expensive, difficult, or not feasible to simulate experimentally. This has made numerical simulation as an efficient way to perform the characterisation of defect in the investigation.

The approaches of thermographic can be implemented in many fields and this has permitted a wider areas of efficient assessment. The utilisation of an infrared camera provides the thermographic images which are susceptible to be interpreted. Through the research, information of the presence of defects can be obtained from the resultant temperature distribution acquired from the thermographic images. The geometrical information of defects are obtained through the analysis of feature extracted from the temperature profiles.

1.2 Problem Statements

Defect detection has been an issue towards the specimen testing, as the growth of conventional NDT technique has limited capability of detecting the defect for in-

service materials. The assessment of the defect such as size, length and angle within the material cannot be accurately addressed for maximum assessment of the structure and the component lifetime prediction. The capability of the stand-alone experimental investigation is limited even though the presence of the defect will prevail. Some simulations and modelling methods need to be issued to support and to prevail accurate results of the experimental as well as developing understanding of the underlying phenomena of defect detection.

1.3 Aims and Objectives

The aim of this research is to bridge the gaps of theoretical (modelling) and experimental investigation of the eddy current thermography testing technique. Generally, the study of the theoretical and experimental in NDT has been separated. This is due to the concern of experimental methods which commonly been applied for industrial applications without knowing the advancement of numerical simulation. To overcome this, the available simulation model are identified as the solution for the complex industrial problems. To meet the current requirements of industries, this research will concurrently investigate the results of modelling via 3D Finite Element Method (FEM) numerical simulations and experimental study. This would lead to diverse applications in NDT which required qualitative information through the assessments of specimens. The surface and angular defects are to be investigated through numerical simulation studies conducted prior to the experiments to provide prediction on responses from the defects using eddy current thermography technique. The numerical and experimental study of the surface and angular defects which have been conducted will become a reference for the investigation on the subsurface defect at the area of HAZ, toe and root of the welded carbon steel specimen. Based on the possibility of the defect detection, the appropriate NDT technique would play a major role to perform visualisation and characterisation of the defects. This will provide the link between the theoretical and experimental study in achieving a better NDT technique.

With corresponding to the aims of this research, the following are the objectives of this research:

1. To identify the features acquired from the experimental results by performing the optimisation parameter of heating time, t and excitation current, I applied on the experiment through the Signal to Noise Ratio (SNR) analysis.
2. To simulate 3D FEM numerical analysis of Comsol Multiphysics, concerning the visualisation of the resulting transient responses from the induction of eddy current in order to detect qualitative information of the defect.
3. To extract features for defect detection of surface defect, angular defect and internal defect on SS316 TRUEFLAW austenitic stainless steel specimen and the subsurface defect at area of HAZ, toe and root on welded carbon steel specimen.

1.4 Structure of Thesis

Chapter 1 gives an outline of the research background, problem statements, aims and objectives of this research.

Chapter 2 begins with reviews on NDT in general and a brief description of the conventional NDT techniques used in industry for defect detection and characterisation. The discussion on the development of the eddy current thermography details with the fundamental concept, experimental setup, modelling approach, advantages and limitations of the system and the applications of the technique for real specimens are also outlined. The explanation of the system will be initiated by a review on the infrared thermography of passive and active approach for NDT.

Chapter 3 provide details about the methodology of the research and the eddy current thermography experimentation parameters. The discussions are sectioned into specimens for testing, system development which involving induction heating system, coil design and camera selection for the investigation. Then the optimisation of the parameter by conducting SNR analysis on the specimen being tested is laid out. The numerical simulation of Comsol FEM Multiphysics and the experimental investigation methodology are reported at the final subsection.

Chapter 4 reports on the results from the research of the defect detection and characterisation. First, the result from the optimisation parameters of heating time and current by adopting Signal to Noise Ratio (SNR) is reported. Then, the optimum parameters of heating time and induction current from the SNR optimisation are applied towards the whole investigation. The results from the investigation on the surface defect of surface cracks, angular defect, internal defect of varies depths and radius and subsurface defect of welded carbon steel specimen are being reported. The investigation results from numerical simulation of 3D FEM Comsol Multiphysics and experimental are then verified through the phenomena of defect detection, data analysis and feature extraction.

Chapter 5 summarises the research, with conclusions of the findings and recommendations for future researches. A brief outline on the scientific contributions for NDT is given, followed by some suggestions on future work based on the current investigation.

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