MAGNETIC FLUX LEAKAGE SYSTEM FOR WIRE ROPE INSPECTION USING BLUETOOTH COMMUNICATION

MUHAMMAD MAHFUZ BIN SALEHHON

UNIVERSITI TEKNOLOGI MALAYSIA

MAGNETIC FLUX LEAKAGE SYSTEM FOR WIRE ROPE INSPECTION USING BLUETOOTH COMMUNICATION

MUHAMMAD MAHFUZ BIN SALEHHON

A thesis submitted in fulfillment of the
requirements of the award of the degree of
Master of Science (Physics)

Faculty of Science
Universiti Teknologi Malaysia

NOVEMBER 2014

ACKNOWLEDGEMENTS

First of all, I want to pay my heartiest gratitude to Almighty Allah for granting us the strength, hardiness and guidance throughout out my study. Indeed, it was through His Consent and Blessing that I have managed to complete this research. Foremost, I would like to express my sincere gratitude to my advisor Associate Professor Md. Supar bin Rohani for his continuous support of my study through motivation, teaching, comment, criticism and providing me with an excellent atmosphere for doing research.

Special appreciation and thanks goes to lecturers who were willing to help in completion this research. Thanks for their brilliant comments and suggestions. I also would like to take this opportunity to express the deepest appreciation to my supportive friends who was always making my life happier. Many thanks also to workshop and laboratory technician for their helping hands.

Last but not least, my heartiest thank you to my parents and beloved family for their moral and financial support. Their sincere and kind help has really enhanced my spirit, determination and enthusiasm to go on with this assignment until the end. I am truly and will always be indebted and grateful to them. Words cannot express how grateful I am to be part of this family, their prayer for me was what sustained me thus far.

ABSTRACT

A wireless data communication Magnetic Flux Leakage (MFL) system for steel wire rope cable inspection has been designed and constructed to facilitate the remote data transferring. The system incorporates permanent magnets and Hall Effect sensor arrays, with its signal processing circuit and data acquisition system. Strong permanent magnetic discs of about 1T are used to magnetize the cable. Hall Effect sensors are arranged in parallel to detect the leakage flux from different angles. The system is battery operated, which is three units of AA batteries function as a power source. Another three units of AA batteries can also be fitted in as the backup power supply. The wireless data communication system has been constructed using Bluetooth module. The signals are digitized using an Emant380 Bluetooth data acquisition module consist of six channels of differential multiplexed analog-to-digital converter, and the data can be stored in computer or Smartphone's memory. Python programming language is used to collect and interpret the data in a graphical form. This system use Tkinter graphical user interface toolkit for the computer while HTML is a platform for full screen user interface display on Smartphone. The screen displays the location and the flaws signal. System was tested and evaluated on various simulated wire rope defects of different depth and width, ranging from 2 mm to 6 mm depth and 1 mm width and also 2 mm to 6 mm width and 2 mm to 3 mm depth. This system has a relatively high sensitivity for the detection of magnetic flux leakage through defects with a depth of 2 mm and 1 mm wide.

ABSTRAK

Sistem pemeriksaan kebocoran fluks magnet (MFL) komunikasi data tanpa wayar untuk pemeriksaan kabel dawai keluli telah direka dan dibina untuk membolehkan pemindahan data jarak jauh. Sistem ini menggabungkan magnet kekal dan susunan penderia Kesan Hall, lengkap dengan litar pemprosesan isyarat dan sistem pemerolehan data. Cakera magnet kekal dengan kekuatan 1T digunakan untuk memagnetkan kabel. Penderia Kesan Hall disusun secara selari untuk mengesan kebocoran fluks dari sudut yang berbeza. Sistem ini beroperasi menggunakan tiga unit bateri AA berfungsi sebagai pembekal kuasa. Tiga unit bateri AA yang lain boleh juga digunakan sebagai bekalan kuasa sokongan. Sistem komunikasi data tanpa wayar telah dibina menggunakan modul Bluetooth. Isyarat didigitkan menggunakan modul pemerolehan data Emant380 Bluetooth enam saluran multipleks berbeza penukar analog-ke-digital, dan data disimpan di dalam memori komputer atau telefon pintar. Bahasa pengaturcaraan Python digunakan untuk mengumpul dan mentafsir data dalam bentuk grafik. Sistem ini menggunakan perkakasan antara-muka pengguna grafik Tkinter bagi komputer manakala HTML sebagai antara-muka pengguna pada platfom paparan skrin penuh telefon pintar. Skrin memaparkan lokasi dan isyarat kecacatan. Sistem telah diuji dan dinilai pada berbagai simulasi kecacatan kabel dengan kedalaman dan lebar pembeza masing-masing pada julat kedalaman 2 mm hingga 6 mm dan 1 mm lebar serta pada julat 2 mm hingga 6 mm lebar dan kedalaman 2 mm hingga 3 mm. Sistem ini mempunyai kepekaan yang tinggi bagi pengesanan kebocoran fluks magnet melalui kecacatan dengan kedalaman 2 mm dan 1 mm lebar.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

H	-	Magnetic field
B	-	Magnetic induction
μ	-	Permeability
μ	-	Micro
M	-	Magnetization
χ	-	Susceptibility
U_i	-	Excitation signal input
U_o	-	Sensing signal output
V	-	Finite speed
B_t	-	Tangential component
B_r	-	Radial component
R_H	-	Hall coefficient
d_H	-	Plate thickness
I	-	Current
V_H	-	Current voltage
R	-	Distance
z_i	-	Number of turns in *i*th coil
$Ø_i$	-	Magnetic flux passing through the core of the *i*th coil
T	-	Time
k	-	kilo
Hz	-	Heartz
V	-	Volt
mm	-	milimeter
sec	-	second
T	-	Tesla

M	-	Mega
m	-	meter
k_H	-	Hall generator sensitivity
tan	-	tangent
π	-	phy
Ω	-	Ohm
VDD	-	IC power supply pin
GND	-	Ground
AIN	-	Analog input
F	-	Farad
COM	-	Component Object Model
CSV	-	Comma Separated Value
Py	-	Python
t	-	Thickness
n	-	Number of electron
e	-	electron

LIST OF ABBREVIATIONS

NDT	-	Non-Destructive Testing
NDE	-	Non-Destructive Evaluation
MFL	-	Magnetic Flux Leakage
AE	-	Acoustic Emission
EM	-	Electromagnetic Testing
DR	-	Digital Radiography
UT	-	Ultrasonic Testing
A/D	-	Analog to Digital
ADC	-	Analog to Digital Converter
NN	-	Neural Network
RBF	-	Radial Basis Function
LMA	-	Loss of Metallic Cross-sectional Area
LF	-	Localized-Flow
DC	-	Direct Current
API	-	Application Programming Interface
RPC	-	Remote Procedure Call
GUI	-	Graphical User Interface
UI	-	User Interface
DAQ	-	Data Acquisition System
N	-	North
S	-	Sourth
PC	-	Personal Computer
Py4A	-	Python for Android
SL4A	-	Script Language for Android
HTML	-	Hyper Text Markup Language

Tk	-	Tkinter
Tcl	-	Tool Command Language
IC	-	Integrated Circuit
RS	-	Radiospares
Ltd.	-	Limited
IDLE	-	Integrated Development Environment

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.0 Introduction

This chapter elucidates the background study of the wire rope, its usage in the industry and the flaws of the ropes when utilized for public purposes. Methods on the cable's damage detection are discussed briefly in this chapter, whereas problems and objectives of this study are stated with sufficient information which enables the execution of this study. In order to ensure that this research can be carried out efficiently, the scope of the study is explained evidently. Last but not least, in order to reveal the contributions of the wire rope to the world of research the significance of the study is framed with precise information.

1.1 Overview

A cable or rope is one of the most ancient inventions invented by humans. Ropes were created either from natural or man-made fibers and metal wires to adapt to our living conditions (Laura, 1995). A wire rope is composed of twisted wires which constitutes of a very complex structure which makes it flexible in bending and combines the strength on the axis and stiffness. Nowadays, modern rope offers a variety of constructions for different levels of diameter with helical complexity (Chaplin, 1995). Ropes are widely used as a major burden in various industrial applications and often involve critical safety components (Wang, 1988). Many ropes degrade due to broken wires and strands caused by fatigue, abrasion or mechanical damage. Since the introduction of security codes, regular inspections were conducted by the responsible authorities.

Wire rope malfunctions lead to damage in expensive equipments and fatalities. Therefore, there are a number of Non-Destructive Testing (NDT) methods to be applied, such as visual inspection, magnetic flux leakage methods, X-ray, ultrasonic and acoustic emission (Kwun, 1988). One of the most common methods is the visual examination and measurement of the rope's external diameter. However by implementing this method, only the flaws on the surface can be detected and it also requires an extensive experiment. This basic methodology must be used as an addition to other test procedures such as electromagnetic (EM) method, a method used on wire ropes and cables which are constructed from synthetic materials.

Another technique for wire rope inspection is radiography testing. This method uses X-rays or radioactive isotopes as a source of radiation. The radiation passes through the material where it will be captured on a film or a digital device. The radiation composed of high energy with short wavelength and produces an electromagnetic wave that is seen as visible light. Once the film image had been processed of varying densities, broken wires and the extent of damage sustained by the core could be determined by the change in density (Halmshaw, 1982).

The screening test volume is also known as the propagation of ultrasonic waves (Ahmet, 2012). This method uses propagation characteristics of high-frequency sound waves caused by horizontal impulsive force of the rope. This technique can detect imperfections or changes in the material properties by applying measurement of various thickness of metal and non-metal rope material.

One of the most conventional approaches to test the wire rope is through Magnetic Flux Leakage (MFL) inspection. MFL is a method used to identify damages in ferromagnetic materials. It is suitable for wire rope tests because of its resolution and high accuracy. This technique involves a magnetic field with the material and measuring the magnetic flux leaking from the surface (Marble, 2009). C. Jomdecha and A. Prateepasen in 2007 introduced the design of modified electromagnetic main-flux for steel wire rope inspection where the electromagnetic field strength can be adjusted to produce a leakage filed from flaws of various large-diameter ropes (Jomdecha, 2007).

Back in 1987, design and operating principles of four new Hall Effect sensors for magnetic testing of steel ropes were presented by E. Kalwa and K. Piekarski. The radial or tangential component of the magnetic flux leakage can be measured using these sensors (Kalwa, 1987). While in 1989, H. R. Weischedel and R. P. Ramsey used modern non-destructive test methods for the qualitative and quantitative inspection (Weischedel, 1989). Based on previous projects involving these topics, it can be concluded that the scope of study is focused more on how to improve the level of sensitivity detection of the equipment used whereas there were not many research conducted on the transferring data network process enhancement.

Thus, through this project, the Magnetic Flux Leakage (MFL) system is established together with the Bluetooth technology application. This system can be used for overhead cables, cable cars, suspension bridge or moving cable in lift hoist. Apart from that, the MFL system also benefits personnel inspector with difficult access cables and hostile environments. This system could be adapted at any locations and the cable can be monitored for the data could be retrieved remotely.

Wire ropes are inspected periodically initial from the time of installation till the time of replacement. The closer the replacement time of the ropes, the more frequent the inspection. For this research, it will be easier to test the cable by using portable devices. In this study, a mobile application was used as a tool for scanning system. The application has been developed with low cost manufacturing processes which results in, people familiarizing in this field for it is important to the industrial sector.

1.2 Problem Statement

The existing Magnetic Flux Leakage (MFL) system requires a set of equipment which is incompatible in many situations. Moreover finding a Bluetooth technology developed with a magnetic flux leakage system detector is extremely rare in this industrial field.

1.3 Objectives

The objectives of this research are as below;

1) To design and construct a portable magnetic flux leakage system for inspecting wire rope samples.
2) To construct a wireless data communication system for transferring data from the device using Bluetooth module.
3) To test and evaluate the cable flaws by using the magnetic flux leakage system.

1.4 Scope

Experiment that were carried out during this research implemented an MFL system for the inspection of steel wire ropes only which follows the maximum diameter up to 20mm the size of pipe installed on the device. It features a wireless Bluetooth system in transferring data within room space. Meanwhile, for the programming part, Python (script language) is used in detecting the device to compare the result. Both end of the cable were clamped at two different tables using an iron vice to which gave the cable sufficient stretch. By stretching the cable it creates the required stimulated defects such as wire breakage. Finally the device goes through the cable in one direction to detect the area of discontinuities.

1.5 Significance of Study

A portable system is generated using the MFL method. Therefore, positive outcome of this study is the ability to detect any defects or discontinuity on steel wire ropes from a distance simply by using the Bluetooth technology. Furthermore, the process of transferring data from the system for data storage is further enhanced in this study so that it is efficient and user friendly. Computer based system or mobile based system are two of the options available that suits the program. There are two slots (main and backup) of batteries for this device and each of them can fill up to three AA batteries. With these two battery slots, it is enough to accommodate the power supply over a period of time to conduct the test.

REFERENCES

Ahmet Hakan Onur, Safa Bakrac and Dogan Karakus (2012). Ultrasonic Waves in Mining Application. *Ultrasonic Waves, Intech, pp 189-210.*

Albert Chan (2011). Comparison of Python for Android and C-Python. *Review of Business and Technology Research, Vol. 5, No. 1, 2011, pp. 163-168.*

Andrea Bergamini and Rouven Christen (2003). A Simple Approach to the Localization of Flaws in Large Diameter Steel Cables.*Nondestructive Evaluation and Health Monitoring of Structural and Biological Systems II, Proceedings of SPIE, Vol. 5047, pp 243-251.*

August Haller (1999). High Resolution Magnetic Induction Wire Rope Test.

Bhaskar B. Ghate and Alex Goldman (2006). Ferromagnetic Ceramics. *Materials Science and Technology.*

Brasseur, G. (2004). Design of an eddy current based crack detection sensor for wire processing applications. *Proceeding of IEEE Sensors 2004 ICSENS-04.*

Casey, N. F. and Laura, P. A. A. (1997). A Review of the Acoustic-emission Monitoring of Wire Rope. *Ocean Engineering, Vol. 24, No. 10, pp. 935-947.*

Chai Xiuli (2009). Structure and character analysis of a new type of steel wire rope NDT detector apparatus. *International Conference on Mechatronics and Automation 08/09.*

Chaplin, C. R. (1995). Failure Mechanisms in Wire Ropes. *Engineering Failure Analysis, Vol 2, No. 1, pp. 45-57.*

Christian, U. and Grosse (2008). Introduction.*Acoustic Emission Testing*.

David Jiles (1998). Introduction to Magnetism and Magnetics Materials. *Second Edition, Chapman and Hall/CRC.*

Duke, J. C., Henneke, E. G., Kierman, M.T. and Grosskopf, P. P. (1991). Study of the stresswave factor technique for evaluation of composite materials. *NDT & E International, Volume 24, Issue 6, pp 325.*

Halmshaw, R. (1982) Industrial Radiology: Theory and Practice (English). *Applied Science Publishers Ltd. London and New Jersey.*

Jiang Xu, Xinjun Wu, and Pengfei Sun (2013). Detecting Broken-wire Flaws at Multiple Locations in the Same Wire of Prestressing Strands Using Guided Waves. *Ultrasonics.*

Jomdecha, C. and Prateepasen, A. (2009). Design of Modified Electromagnetic Main flux for Steel Wire Rope Inspection. *NDT&E International 42, pp 77–83.*

Kalwa, E. and Piekarski, K. (1987). Design of Hall-effect sensors for magnetic testing of steel ropes. *NDT International, Volume 20, Number 5, pp 295-301.*

Kalwa, E. and Piekarski, K. (1987). Design of inductive sensors for magnetic testing Of steel ropes. *NDT International, Volume 20, Number 6, pp 347-353.*

Kalwa, E. and Piekarski, K. (1988). Determination of flaws located at different depth levels in the cross-section of steel rope. *NDT International, Volume 21, Issue 2, pp 77-82.*

Kris Marble (2009). Investigation of the Magnetic Flux Leakage Signatures of Dents and Gouges. *Queen's University Kingston, Ontario, Canada, Master Thesis.*

Kwun, H. and. Burkhardt, G. L. (1988). Feasibility of Nondestructive Evaluation of Synthetic or Wire Ropes Using a Transverse-impulse Vibrational Wave. *NDT International, Volume 21 Number 5, pp 341-343.*

Laura, P. A. A. (1995). Evaluating The Structural Condition of Synthetic and Metallic Cables. *Ocean Engineering, Vol. 22, No. 6, pp. 551-562.*

Magnetic Materials. *Materials Handbook 2008, pp 487-517.*

Mark Willcox and George Downes (2003). A Brief Description of NDT Techniques. *NDT Equipment Limited.*

Mohd. Rozni bin Mohd Yusof (2005). The Design and of a Computerised Magnetic Flux Leakage System for Electromagnetic Inspection of Ferromagnetic Specimens. *Universiti Teknologi Malaysia, Master Thesis.*

Qingsong Cao, Dan Liu, Yuehai He, Jihui Zhonand John Codrington (2012). Nondestructive and Quantitative Evaluation of Wire Rope Based on Radial Basis Function Neural Network Using Eddy Current Inspection. *NDT&E International 46, pp 7–13.*

Roland Verreet and Isabel Ridge (2005).Wire Rope Forensic.

Teong Ham Chew (2013). “Private Communication”. *UniversitiTeknologi Malaysia.*

Wang Yangsheng, Shi Hanmin and Yang Shuzi (1988). Quantitative Wire Rope Inspection. *NDT International, Volume 21 Number 5, 337-340.*

Wang Ming-sheng and Chen Zheng-shi (2011). Researching on the Linear X-ray Detector Application of in the Field of Steel-core Belt Conveyor Inspection System.*International Conference on Electric Information and Control Engineering 2011.*

Weischedel, H. R. (1985). The Inspection of Wire Ropes in Service: A Critical Review. *Materials Evaluation, Vol. 43, No 13, pp 1592-1605.*

Weischedel, H. R. and Ramsey, R. P. (1989). Electromagnetic testing, a reliable method for the inspection of wire ropes in service. *NDT International, Volume 22, Number 3, pp 155-161*.

Weischedel, H. R. (1998). Electromagnetic Wire Rope Inspection – Resolution is Important. *Materials Evaluation, pp 1297-1301*.

Wong Toh Ming (2004). Design and Construction of Magnetic Flux Leakage Inspection System for Ferromagnetic Material. *UniversitiTeknologi Malaysia, Master Thesis.*

Yoshihiro Mizutani, Sota Sugimoto, Ryosuke Matsuzaki and Akira Todoroki (2009). Fundamental Study on Integrity Evaluation Method for COPVS by Means of Acoustic Emission Testing. *J. Acoustic Emission, 27, pp 89-97*.

Zhong Xiao-yong and Zhang Xiao-hong (2012). Research of Non-destructive Testing of Wire Rope Using Magnetic Flux Leakage. *Applied Mechanics and Materials, Vol. 189, pp 255-259.*