UNIVERSITI PUTRA MALAYSIA

ANALYSIS OF HEAD LENGTH EFFECT OF WIRE ROPE SENSOR ON OUTPUT VOLTAGE

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By

NOOR HASMIZA BT HARUN

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

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Dedication

TO MAK, ABAH AND FAMILY

ESPECIALLY TO MY HUSBAND, ROZAIMI ABDUL JALIL AND DAUGHTER, SUFIYA DINA IMANI

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

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April 2008

Chairman: Norhisam Misron, PhD

Faculty: Engineering

Wire rope are used extensively in industrial applications involving lifting machines such as lift system, cable car system as well as crane services. In many cases, failure of a wire rope could lead to expensive damage to equipment or even to loss of life. Structural integrity of the wire rope is to be monitored to safe guard human lives. Regular periodic inspection is necessary for optimum safe utilization.

Apart from visual inspection, the non destructive test methods are available to check the condition of this wire rope. Various methods have been used for wire rope testing such as eddy current, ultrasonic and radiographic. However, each method has some drawbacks in their application.

Currently, there is no specific tool to design the wire rope sensor. Trial and error method was used to design the wire rope sensor and it will consume longer time for prototyping and fabricating the sensor. This method does not offer rapid performance evaluation of the designed sensor and it will cause the process of improving the efficiency of the sensor will be slower. Therefore, development of a model to design

the wire rope sensor has been proposed. This model is able to investigate variable parameter involved in designing the wire rope sensor and it will speeding the process of prototyping the wire rope sensor.

In this research, a fabricated wire rope sensor based on electromagnetism principles has been analyzed. The sensor applies the theory of magnetic circuit for the crack detection operation. This is an added feature to the sensor as the magnetic circuit does not need any energy supply to be energized which indirectly reduces its energy consumption. This sensor is a passive type sensor and its structure is very simple. It is made up of three main components; sensor head, center yoke rounded with copper wire and a set of permanent magnet. The sensor will only produce a signal when there is a relative movement between the sensor head and the tested wire rope.

Derivations of theoretical calculations using permeance method was done to obtain a tools that manages to study the physical structures behaviors of the sensor. Finite Element Method (FEM) simulations and laboratory experiments have been conducted to observe the effects of head length to the output voltage of the sensor.

The objective of this research is to perform the analysis of head length, L_h effect of wire rope sensor on output voltage was successfully achieved. A theoretical equation for the voltage induced by the sensor has been deduced using permeance method. Finite Element Method (FEM) simulation and laboratory experiments were done to observe the effects of head length of the sensor head to the output voltage of the sensor. Comparison between simulation result, theoretical calculation and laboratory

experiment shows almost identical results. The analysis is necessary to obtain the best design for the wire rope sensor that would produce high output voltage.

Abstrak thesis yang dikemukakan kepada Senat Universiti Putra Malaysia
sebagai memenuhi keperluan untuk ijazah Master Sains

ANALISIS KESAN PANJANG MATA PENGESAN WAYAR KABEL KEPADA VOLTAN KELUARAN

Oleh

NOOR HASMIZA BT HARUN

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Wayar kabel digunakan secara meluas dalam aplikasi industri seperti elevator, lif, kereta kabel dan kren. Dalam beberapa kes, kegagalan wayar kabel boleh mengakibatkan kerosakan kepada peralatan mahupun nyawa manusia. Keutuhan struktur wayar kabel haruslah dipantau untuk keselamatan manusia. Pemeriksaan berterusan adalah perlu untuk mengoptimumkan keselamatan.

Selain daripada pemeriksaan visual, kaedah ujian tanpa kerosakan juga digunakan untuk memeriksa keadaan wayar kabel. Pelbagai kaedah telah digunakan untuk pemeriksaan wayar kabel seperti arus “eddy”, ultrasonic dan radiografi. Walaubagaimanapun, setiap kaedah mempunyai kelemahan dalam aplikasi.

Sekarang ini, tiada kaedah spesifik untuk mereka pengesan wayar kabel. Kaedah cuba dan salah telah digunakan untuk mereka pengesan wayar kabel dan ia menggunakan banyak masa untuk membuat protaip dan fabrikasi pengesan tersebut. Kaedah ini tidak menawarkan penilaian prestasi pantas dan ini akan menyebabkan

proses meningkatkan kecekapan pengesan akan menjadi lambat. Oleh sebab itu, pembangunan sebuah model untuk mereka pengesan wayar kabel telah dicadangkan. Model ini berupaya untuk memeriksa pelbagai parameter yang digunakan untuk mereka pengesan wayar kabel dan ini akan mempercepatkan proses membuat prototaip pengesan wayar kabel.

Dalam kajian ini, pengesan wayar kabel berasaskan prinsip elektromagnet telah dianalisa. Ia menggunakan teori litar magnet untuk operasi mengesan keretakan. Pengesan ini tidak memerlukan bekalan kuasa dan secara tidak langsung akan mengurangkan penggunaan kuasa. Pengesan ini adalah pasif dan strukturnya ringkas. Ia terdiri daripada tiga komponen penting: mata pengesan, tiang tengah yang dikelilingi dengan wayar kuprum dan juga sepasang magnet kekal. Pengesan ini hanya akan mengeluarkan isyarat jika terdapat pergerakan di antara mata pengesan dan wayar kabel.

Pembuktian pengiraan secara teori menggunakan kaedah galangan telah dijalankan untuk mendapatkan alat yang mampu mengkaji sifat struktur fizikal pengesan tersebut. Simulasi FEM dan eksperimen makmal telah dilakukan untuk melihat kesan panjang mata kepada voltan keluaran pengesan.

Objektif penyelidikan ini adalah untuk melaksanakan analisa kesan panjang mata pengesan wayar kabel kepada voltan keluaran telah berjaya dicapai. Pengiraan secara teori untuk voltan keluaran telah diperolehi menggunakan kaedah galangan. Simulasi FEM telah dilakukan untuk melihat kesan mata pengesan kepada voltan keluaran pengesan wayar kabel ini. Perbandingan di antara keputusan yang diperolehi

daripada simulasi FEM, pengiraan teori dan eksperimen makmal memberikan keputusan yang sama. Analisis ini adalah perlu untuk mendapatkan rekabentuk terbaik pengesan wayar kabel yang yang boleh menghasilkan keluaran voltan yang tinggi.

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I certify that an Examination Committee met on (April, 3rd 2008) to conduct the final examination of Noor Hasmiza Harun on her Master of Science thesis entitled "Analysis of head length effect of wire rope sensor on output voltage" in accordance with University Putra Malaysia (Higher Degree) Act 1980 and University Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

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

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Date:12 June 2008

DECLARATION

I declare that the thesis is my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously, and is not concurrently submitted for any other degree at UPM or other institutions.

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NOOR HASMIZA BT HARUN

Date: 23 May 2008

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LIST OF ABBREVIATIONS

L_h	Head length
g_{hl}	Head length gap
g_c	Coil gap
μ_0	Permeability of air = 4π x 10^{-7}
P_1	Permeance between coil gap
P_2	Permeance between head length gap
P_3	Permeance at the wire rope
P_c	Permeance at the crack
P_{cy}	Permeance at cylinder
P_r	Permeance at ring
w_1	Width of the P_1
l_1	Length of the P_1
w_2	Width of the P_2
l_2	Length of the P_2
D	Diameter of the wire rope
L_c	Length of the crack
G	Gap of the ring
V_s	Supply voltage
B	Magnetic density
ϕ_t	Total flux flowing
A	Magnetic area
I_t	Total current
ϕ_1	Flux flowing at P_1
ϕ_2	Flux flowing at P_2
ϕ_3	Flux flowing at P_3

$\mathcal{R}_1$	Reluctance of P_1
$\mathcal{R}_2$	Reluctance of P_2
$\mathcal{R}_3$	Reluctance of P_3
θ_c	Angle of crack = $x/35$
V	Output voltage of the wire rope sensor
N	Number of coil turn
$\frac{\partial \phi_3}{\partial t}$	Flux changes per second

CHAPTER 1

INTRODUCTION

1.1 Background of the Wire Rope Sensor

Wire ropes are used widely in industrial applications such as elevators, lift system, cable car system and crane services (Park and Park, 2002) and are often safety-critical components. In many cases failure of a wire rope could lead to expensive damage to equipment or even to loss of life (Yangsheng, Hanmin and Shuzi, 1988). Due to the long duration usage, surface as well as the internal of wire ropes may have defects (Zawada, 1999). Therefore, there is an obvious need to check the condition of the wire ropes regularly to avoid any fatal accident due to its internal flaw (Moriya, Sugawara and Tsukada, 2004).

A recent statistical of over 8000 laboratory and field test records indicates that visual wire rope inspections are frequently unreliable, and that visual methods must be considered, in many cases, questionable as a sole means of inspection (Weischedel, 1990). Apart from visual inspection, the non destructive test methods are available to check the condition of these wire ropes (Placko and Dufour, 1993). Various methods have been used for wire rope testing such as eddy current, ultrasonic and radiographic. However, each method has some drawbacks in their application.

Eddy current method, for example, works on the transformer principles, making this method complex. The sensor is based on the induction of voltage in a coil. Therefore, an excitation coil would generate an alternating magnetic field that causes eddy currents in the tested wire rope. Based on the excitation frequency used, eddy current would induce a magnetic field itself. The resulting field of both the excitation field

and the field caused by the eddy currents, induces a voltage in the measurement coils. The pulse-echo ultrasonic techniques of a longitudinal ultrasonic wave applied from one of the ends of the wire, propagating along it as a composite wave is one of the recent techniques used in the wire rope inspection. However, studies were performed looking for frequencies appropriated for giving good conditions to get good sensitivity and transmission and low attenuation (Desimone, Katchadjian, Tacchia and Giacchetta, 2001). Besides, ultrasonic testing requires sophisticated and high end instrument for signal detection and processing.

Radiography is another method used in the wire rope inspection. However, it is very hazardous and requires competent personnel for safety inspection. The radiographic test method illustrates the volume density of a test body in a two dimensional image. Gamma rays radiated by a radioactive isotope penetrate the cable and expose, in a more or less attenuated form, an x-ray film placed on the other side of the cable. Small wires fractures, corrosion and damage cannot normally be detected (Prakash, 1980).

In this research, a wire rope sensor based on electromagnetism principles has been developed. This sensor is a passive type sensor and its structure is very simple. It is made up of three main components; sensor head, center yoke rounded with copper wire and a set of permanent magnet. The sensor would only produce a signal when there is a flux change due to time that occurs between the sensor head and the wire rope. Finite Element Method (FEM) simulations and theoretical calculations using permeance method have been made to design the sensor and verify its efficiency. The observations are followed by sets of experiment for the wire rope sensor with two

different sizes of the head length where head length, L_h is defined as the length of the sensor head. Generally, the main objective of the research is to study the effects of designed parameter to the output voltage of the sensor. Specifically, the effects of the head length, L_h to the output voltage of the sensor have been observed in this research.

1.2 Problem Statement

Wire ropes are inspected periodically from the time they are installed until the time they are replaced. The frequency of inspection depends on the character and magnitude of the load carried by the rope and the condition of the rope. The closer to the replacement time of the rope, the more frequently and accurately the inspection has to be performed. The test procedure should be able to determine the actual strength of the rope and whether or not the replacement criteria apply (Kalwa and Piekarski, 1987).

Apart from careful visual examination and measurements of the external diameter, the nondestructive test methods available utilize electromagnetic fields, X-rays or mechanical waves (Wait, 1979). For example, in eddy current non destructive testing, an exciting coil generates eddy currents in the metal, which is being tested. The eddy currents are perturbed by defects in the metal, and the results is reflected in the magnetic field above the metal surface. In order to detect perturbations in this field one can observe changes in the impedance of the exciting coil or in the voltage induced in a secondary coil, if separate coils are used for excitation and detection. Unfortunately, in many important cases the changes are usually very small. Precise

measurements of small variations in relatively large values of impedance are difficult. Therefore, it requires additional detection devices such as differential eddy current probes (Chady and Enokizono, 1999). Thus, this method is quiet complex and inconvenience for field testing. The pulse-echo ultrasonic is one of the recent techniques used in wire rope inspection. However, studies were performed looking for frequencies appropriated for giving good conditions to get good sensitivity and transmission and low attenuation (Desimone, Katchadjian, Tacchia and Giacchetta, 2001). Finally, the radiographic test method illustrates the volume density of a test body in a two dimensional image (Prakash, 1980). However, it is very hazardous and requires competent personnel for safety inspection.

In this research, an analysis on the constructed wire rope sensor based on electromagnetism principles has been done (Shin, 2006). The advantages of this wire rope sensor are it is a passive type sensor and its structure is very simple. Besides, its highlighted features such as low cost, low power consumption and portable makes it very convenient for wire inspection. However, it is necessary for the researcher to design a wire rope sensor that will provide better performance.

In order to speed up the process of designing, an analysis based on magnetic circuit analysis on the designed parameter of the wire rope sensor has been done. The analysis is necessary to provide the researcher with a tool that manages to study the physical structure behavior of the wire rope sensor. Derivation of theoretical equation using permeance method was done based on the fabricated model by (Shin, 2006). Then, it was analyzed using Finite Element Method (FEM) simulation and laboratory experiment. Both methods were used to observe the effects of designed parameter of

the wire rope sensor to the output voltage of the sensor. Specifically, the effects of the head length, L_h of the sensor head to the output voltage of the sensor have been chosen as the main designed parameter to be observed in this analysis.

1.3 Objectives

The aim of this study is to provide an analysis of head length effect of wire rope sensor on output voltage using magnetic circuit analysis. There are two methods used in the magnetic circuit analysis in this research; derivation of the theoretical equation using permeance method and Finite Element Method (FEM) simulation. For derivation of the theoretical equation derived using permeance method, analysis has been done to the parameters involved in the equation to observe their effects to the output voltage of the sensor and focused is made to study the effects of head length of the sensor head to the output voltage. For FEM simulation, three effects of the designed parameter have been observed; effects of air gap, effects of coil gap and the back yoke saturation effects. Those effects have been studied to obtain the most similar magnetic resistance in the wire rope and it is necessary to study the effects of head length of the sensor head to the output voltage. Sets of laboratory experiment are also being conducted to study the effects of head length of the sensor head to the output voltage of the sensor. For conclusion, the major targets of this research can be summarized as:

1. To derive the equation of the output voltage of the sensor using permeance method and study the effects of designed parameter to the output voltage.
2. To perform the FEM simulation and study the effects of designed parameter to the output voltage of the sensor.