UNIVERSITI PUTRA MALAYSIA

DEVELOPMENT OF LINEAR DISPLACEMENT SENSOR USING MEANDER COIL AND PATTERN GUIDE

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LINEAR DISPLACEMENT SENSOR USING MEANDER COIL AND PATTERN GUIDE

By

NORRIMAH BT ABDULLAH

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

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Dedication

TO MY HUSBAND, ARZANEE SAIDIN

MY CHILDREN, NURFAKHIRA IWANI, NURSYAHIRAH SYAFIQAH, MUHAMMAD NAZHAN FAHMI

AND

MY FAMILY

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirements for the degree of Master of Science

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Chairman: Norhisam Misron, PhD

Faculty: Engineering

In modern industrial production processes, the actual displacement of fast moving objects needs to be detected and it is ideally done without mechanical contact. There exists a variety of suitable sensors that provide an output signal (voltage or current) proportional to the displacement of the sensor target. The sensors must also meet the industrial requirements such as reliability, ruggedness and measuring range. To find the best sensor for the displacement purpose, accuracy, miniature size and insensitive to the environment factor is also very important to be considered.

Magnetic sensor based on inductive concepts, has been widely used technique for measuring displacement. The most significant advantage of magnetic-inductive sensor in industrial applications is the immunity against oil, water, dirt, moisture and interference field. In addition, current development and trends in the industrial fields, especially micro-system and micro-mechanical applications like robotics and manipulator applications require utterly small and fully integrated displacement sensor.

Linear motor is an example of linear actuator. The basic function of linear motor is for to generating a controlled physical linear displacement. Linear motor is essentially rotary electric motor laid down on flat surface. Linear motor, actuators converts an electrical signal (voltage or current) to mechanical displacement. This conversion is mostly used in robotics. Linear motor generally consists of two parts, a stationary track or “platen” and a moving part or “forcer”.

In this study, displacement sensor based on the magneto-inductive concepts has been developed. It consists of sensor head and pattern guide. The structure of the sensor is based on the structure of the linear motor. The sensor head structure is based on the forcer and the pattern guide is based on the platen of the linear motor. In common systems, linear motor and the sensor have separate platen and forcer. Research focuses on integrating the sensor and the linear motor as a one body, in which the pattern guide of the sensor will be a platen and the sensor head will be a forcer of the linear motor. Therefore, the whole structure will be simple and thus reduce the overall cost and size.

The combination of the sensor head and pattern guide is important to get the high accuracy of the positioning. The sensor head is made from the copper material while the pattern guide is made from soft iron SS400. Six configuration of the sensor head have been designed and fabricated based on their coil gap, G_m. To model the actual linear displacement sensor, the mathematical equation of the output voltage of the sensor has been derived. This equation describes the characteristic of the output voltage for linear displacement sensor based on the displacement of the pattern guide when certain input signal is applied to the sensor system. From the equation, the effect of input frequency on the output voltage of the sensor was analyzed and has been compared with the measurement data.

The effect of the output voltage on the displacement of the pattern guide is observed for the open coil and the close coil condition. The results obtained have been analyzed in terms of sensitivity, hysteresis and linearity. The sensitivity of the sensor is calculated based on the highest changes of the output voltage for various input frequency, coil gap and exciting voltage.

The output voltage for various input frequencies, exciting voltage and coil gap also have been compared in terms of hysteresis and linearity. The hysteresis of the output voltage for the sensor is based on the deviation of the sensor output at a specific point of input signal when it is approached from opposite direction. The linearity of the output voltage for the sensor is calculated using best-fit straight line (BPSL) method as being explained in the sensor characteristic in the Chapter 2.

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

PEMBINAAN PENGESAN ANJAKAN LELURUS DENGAN MENGGUNAKAN GEGELUNG BERLIKU DAN CORAK PENUNJUK

Oleh

NORRIMAH BT ABDULLAH

JULAI 2008

Pengerusi: **NORHISAM MISRON, PHD**

Fakulti: **Kejuruteraan**

Dalam industri proses pengeluaran moden, anjakan sebenar objek yang bergerak laju perlu dikesan, dan secara unggulnya ia dilakukan tanpa sentuhan mekanikal. Terdapat pelbagai jenis pengesan yang sesuai dan yang menghasilkan isyarat keluaran (voltan atau arus) yang berkadaran dengan anjakan sasaran pengesan. Pengesan juga mestilah menepati keperluan industri seperti kebolehpercayaan, tahan lasak dan julat pengukuran. Bagi mendapatkan pengesan terbaik untuk tujuan anjakan, ketepatan, size kecil dan tidak sensitif kepada faktor persekitaran adalah penting untuk dipertimbangkan.

Pengukuran anjakan, kedudukan dan pergerakan menggunakan pengesan magnetik berasaskan konsep induktif adalah teknik yang banyak digunakan. Kelebihan utama pengesan magnetik-induktif dalam penggunaan industri adalah kekebalan terhadap minyak, air, kotoran, kelembapan dan gangguan medan. Tambahan pula, penghasilan arus dan cara penggunaan dalam bidang industri, terutama penggunaan system-mikro dan mikro-mekanikal seperti applikasi robotik dan pengguna memerlukan pengesan anjakan yang kecil dan bersambung keseluruhannya.

Motor lelurus adalah satu contoh bagi aktuator lelurus. Fungsi asas motor lelurus adalah digunakan untuk menghasilkan anjakan lelurus fizikal secara terkawal. Motor lelurus pada asasnya adalah motor elektrik berputar yang terletak pada permukaan rata. Motor lelurus adalah aktuator yang menukarkan isyarat elektrik (voltan dan arus) kepada anjakan mekanikal. Penukaran sedemikian banyak digunakan dalam robotik. Motor lelurus umumnya terdiri daripada dua bahagian: landasan statik atau “platen” dan landasan bergerak atau “forcer”.

Dalam kejadian ini, pengesan anjakan berasaskan magneto-induktif konsep telah dihasilkan. Ia adalah gabungan mata pengesan dan corak penunjuk. Struktur pengesan adalah berasakan struktur motor lelurus. Struktur mata pengesan adalah berasaskan “forcer” dan corak penunjuk pula berasaskan “platen” motor lelurus. Biasanya, motor lelurus dan pengesan mempunyai “forcer” dan “platen” yang berasingan. Walaubagaimanapun penyelidikan ini menumpukan kepada penghasilan pengesan sebagai sebahagian daripada motor lelurus dimana corak penunjuk pengesan berfungsi sebagai “platen” motor lelurus dan dalam masa yang sama berfungsi sebagai corak penunjuk. Manakala mata pengesan berfungsi sebagai “forcer” motor lelurus dan dalam masa yang sama berfungsi sebagai mata pengesan. Maka keseluruhan struktur akan menjadi ringkas, dan seterusnya dapat mengurangkan kos dan saiz.

Kombinasi mata pengesan dan corak penunjuk adalah penting untuk mendapatkan ketepatan kedudukan yang tinggi. Mata pengesan diperbuat daripada bahan tembaga manakala corak penunjuk diperbuat daripada besi lembut SS400. Ada enam mata pengesan yang direka cipta dan dihasilkan berpandukan kepada ruang gelung pengesan. Struktur pengesan anjakan lelurus telah direka cipta dan dihasilkan untuk tujuan eksperimen.Bagi mendapatkan model pengesan anjakan lelurus sebenar, pembuktian persamaan matematik voltan keluaran pengesan telah dibuat. Tujuan memodelkan system adalah untuk mendapatkan persamaan matematik yang tepat bagi voltan keluaran pengesan anjakan lelurus. Persamaan ini menerangkan sifat voltan keluaran pengesan anjakan lelurus berasaskan anjakan corak penunjuk selepas masukan dikenakan kepada system pengesan. Daripada persamaan tersebut, kesan frekuensi masukan keatas voltan keluaran pengesan dianalisis dan dibandingkan dengan data pengukuran.

Eksperimen dijalankan untuk tujuan permerhatian. Kesan anjakan corak penunjuk kepada voltan keluaran pengesan diperhatikan untuk keadaaan gegelung terbuka dan gegelung tertutup. Sifat voltan keluaran bagi berbagai frekuensi masukan, ruang gegelung dan voltan ujaan diperhatikan. Keputusan daripada keadaan gegelung terbuka dijadikan rujukan untuk permerhatian bagi keadaan gegelung tertutup. Keputusan yang diperolehi dianalisis dari segi sensitiviti, “hysteresis” dan kelelurusan. Sensitiviti sensor dikira berdasarkan perubahan tertinggi voltan keluaran untuk berbagai frekuensi masukan, ruang gegelung dan voltan ujaan.

Voltan masukan untuk berbagai frekuensi masukan, ruang gegelung dan voltan ujaan juga dibandingkan dari segi "hysteresis" dan kelelurusan. Hysteresis voltan masukan untuk pengesan adalah sisihan keluaran pengesan pada titik yang spesifik bagi isyarat masukan bila ia masuk dari arah bertentangan. Kelelurusan voltan masukan untuk pengesan dikira menggunakan kaedah garisan lurus terbaik seperti yang diterangkan dalam sifat pengesan di bab dua.

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I certify that an Examination Committee met on (April, 1st 2008) to conduct the final examination of Norrimah Bt Abdullah on his Master of Science thesis entitled "Development of linear displacement sensor using meander coil and pattern guide" 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: 11 September 2008

DECLARATION

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

NORRIMAH ABDULLAH

Date: 22 August 2008

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LIST OF ABBREVIATIONS

E_c	Exciting coil
S_c	Search coil
G_m	Coil gap
G_{ee}	Coil gap between exciting coil –exciting coil
G_{ss}	Coil gap between search coil –search coil
G_{es}	Coil gap between exciting coil –search coil
μ_r	Permeability of iron core
μ_0	Permeability of air = $4\pi \times 10^{-7}$
V_{sc}	Output voltage of the linear displacement sensor
V_{ex}	Exciting voltage of the linear displacement sensor
f	Input frequency
H	Hysteresis
L	Linearity
B	Magnetic density
ϕ	Total flux induced
A	Cross section area of the sensor coil
V	Induced voltage
N	Number of coil turn
$d\phi/dt$	Rate of change magnetic flux
k	Magnetic coupling coefficient
R	Coil resistance
L	Coil inductance
I	Coil current
l_c	Coil length

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

This section discussed on the definition and application of the linear displacement sensor. There are the displacement, the displacement sensor, the meander coil and the pattern guide, the linear motor and the introduction of the research project.

1.1.1 Displacement

The measurement on the displacement of physical object is essential for many applications: process feedback control, performance evaluation, transportation traffic control, robotic and security system. Displacement means moving from one position to another for specific distance or angle (Fraden (1993)).

1.1.2 Displacement sensor

The displacement sensor may be part of a more complex sensor where the detection of movement is one of the steps in a signal conversion. An example is a capacitive pressure is translated into a displacement of a diaphragm, and the diaphragm displacement is subsequently converted into an electrical signal representing pressure. There are various types of linear displacement sensor with different types of principles. It is depends on the application of the sensor. For examples: capacitive based sensor, laser based sensor, optical sensor, inductive sensor and magnetic sensor. In this research, the linear displacement sensor has been developed based on the magnetic sensor.

There are varieties of the magnetic sensor with different concept for the linear displacement detection. Examples of the magnetic sensor for the linear displacement detection are reed switches, Hall Effect sensors, magnetoresistive sensors. The detail of the magnetic sensor is discussed in Chapter two. In this research, magnetic sensor based on the magnetic-inductive concept with meander coil type has been discussed for linear displacement detection. The detail explanation for the structure and the basic principles of the sensor development is discussed in Chapter three.

1.1.3 Meander coil and pattern guide

The linear displacement sensor that has been developed is consists of the sensor head and the pattern guide. Meander type coil is used as the shape of the sensor head. The pattern guide is designed in triangle shape.

1.1.4 Linear motor

In recent years, linear motor has been widely used in industrial and commercial products. Many machine tools and industrial equipments are now adopting linear motor in the design due to the advantages offered by this device. Simple structure of linear motor offer high flexibility to the machine in terms of size and space (Backman (2005)). Fewer components in motor structure and little requirement of lubrication made installation and maintenance easy.

Linear motor generally consists of two parts; a stationary track or “platen” and a moving part or “forcer”. Linear motor can be assembled as a stand alone linear motor or as a complete stage, built with a housing or enclosure with linear bearings, limit switches, cable track/carrier, protective bellows and linear encoder in a wide of lengths (Baldor Linear Motor and Stage (2006)).

Linear motors provide direct linear motion and normally are designed with specific length. For a typical linear motor driver, a positioning sensor is usually attached to the motor which provides feedback positioning signal to the controller. This sensor is typically expensive and normally has the same length with the motor. The price for this type of sensor increases with the size, which eventually increase the cost of linear motor package (Panahi, Arefeen and Yu (1997)).

Due to the high cost, the new approach was presented to making a sensor as a one part of the linear motor. A meander coil type Linear Sensor (MLS) has been used to detect the position of a Linear Pulse Motor (LPM)'s mover. This sensor uses a LPM's stator as the scale (Wakiwaka, Yanase and Nishizawa (1996)), so it is possible to be combined with the LPM. Thus, it will reduce the whole size of the LPM, and thus reduced the overall production costs.

1.1.5 Introduction of the research project

In this research linear displacement sensor using meander coil and pattern guide has been proposed and developed for application on the linear motor. Linear displacement sensor can detect displacement in the linear motor. This sensor uses track of the linear bearing of linear motor as a pattern guide. So, it is possible to be combined with the linear bearing of the linear motor. The objective is to produce a linear displacement sensor as one part of the linear motor and thus reduce the whole size and cost of the linear motor system.

To find the best sensor for the detection of displacement in linear motor, the accuracy factor is very important to be considered. Although the laser sensor is widely used in the modern industry, but in term of the accuracy it is less accurate if any obstacle exists in between of the detection objects. It is also not suitable for the harsh environment. Optical sensor also useful when high accuracy measurement is required, but it is not suitable for harsh environment and also expensive (Jagiella, Biermann, Topkaya (1992)).

Measuring the displacement, position and travel using magnetic sensor based on the inductive concepts widely used technique. In comparisons to optical and laser sensor technologies, the biggest advantage of magnetic-inductive sensor in industrial applications is the immunity against oil, water, dirt, moisture and interference field. In addition, current development and trends on the industrial fields, especially micro-system and micro-mechanical applications like robotics and manipulator applications, require utterly small and fully integrated displacement sensor (Erg, Hinz and Preusse (1991)).

In the development of the sensor, the meander coil based on the copper has been proposed as a sensor head. This sensor head consists of exciting coil *E*c and search coil *S*c, which will be show in Figure 3.2 on chapter three. For the pattern guide, the soft iron SS400 was chosen. The function of the sensor head is to produce the electrical signal by the magnetic field, and pattern guide is to allocate the position of the sensor head. The best combination of the sensor head and pattern guide is important to get the high accuracy of the positioning.