UNIVERSITI PUTRA MALAYSIA

A SENSORLESS POSITIONING SYSTEM FOR LINEAR DC MOTOR

EZRIL HISHAM B. MAT SAAT

A SENSORLESS POSITIONING SYSTEM FOR LINEAR DC MOTOR

By

EZRIL HISHAM B. MAT SAAT

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

JULY 2008

Dedication

TO MY FAMILY AND MY WIFE

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

A SENSORLESS POSITIONING SYSTEM FOR LINEAR DC MOTOR

By

EZRIL HISHAM B. MAT SAAT

JULY 2008

Chairman: Norhisam Misron, PhD

Faculty: Engineering

In recent years, linear motor has gained popularity as linear motion drive in industry and factory automation which provides an alternative to conventional rotary motor. This development was encouraged by the advantages offered by linear motors such as flexibility in size and design, clean and silent operation, ease of maintenance and deliver high performance for applications requiring linear motion. However, the main constraint for system designers to consider linear motors in their application is the cost for every complete package of linear motor. Generally, linear motors are expensive than their counterparts due to the number of permanent magnet used in the motors and the sensory technologies used for positioning system.

Linear motors provide direct linear motion and normally are designed with specific length which requires more permanent magnets than rotary motor. Therefore, the costs of linear motors increase with the length of the motor itself. For a typical linear motor driver, a positioning sensor, usually attached to the motor, provides feedback positioning signal to the controller. This sensor is 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 motors.

For some applications, where positioning is not too critical such as robot end gripper, the high precision and expensive positioning sensor is not necessary. Removing this sensor from the system reduces the overall system cost, thus encouraging more development and application of linear motors. This research and study proposes a sensorless positioning system for linear DC motor (LDM). The ideas to control the position of the LDM are by controlling the current supplied to the motor. The technique used to control the current is by manipulating Pulse Width Modulation (PWM) signal which is generated by a microcontroller circuit based on Atmel AVR ATmega8535 processor.

A simple model of LDM was constructed for experimental purposes. A mechanical spring was used in the motor design to absorb the force produced by the motor. The displacement of the spring will then be used to determine the position of the motor. Due to the harmonic oscillation produced in mass-spring system, the position of the motor oscillates before reaching the final desired position. In order to eliminate the harmonic oscillation effect, a few variants pattern of PWM signals are used to drive the motor. These variant patterns are single stage, dual stage, triple stage and quadruple stage. The variant patterns of PWM signals were created by combining multiple values of duty cycle running in a single PWM signal.

A mathematical model for constructed LDM has been derived based on damped force oscillation of mass spring system theory. The equation of motion for LDM is then simulated using Matlab software. The time response of the system based on simulation results has been studied and proper adjustment to control parameters has been made to improve the rise time, overshoot percentage and steady state error. The adjusted driving parameters are then transferred to microcontroller unit for actual laboratory experiment.

The objective of this research to develop a sensorless positioning system for LDM which include a motor driver and control approach was successfully achieved. Comparison between simulation results and laboratory experiment shows almost identical results. Linear relation between motor position and timing parameters used in control algorithms has been studied and linear equations have been derived. These linear equations will be converted into microprocessor programming as feed-forward control algorithms. Any desired motor position can be fed into the system and microprocessor unit will generates a proper PWM driving signal to the motor. The developed system can be used for any low cost applications which do not require precise positioning.

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

SISTEM PENETAPAN KEDUDUKAN TANPA PENDERIA BAGI MOTOR LINEAR DC

Oleh

EZRIL HISHAM B. MAT SAAT

FEBRUARY 2007

Pengerusi: **DR. ENG. NORHISAM MISRON**

Fakulti: **Kejuruteraan**

Kebelakangan ini, motor linear telah mula mendapat perhatian sebagai pemacu gerakan linear di industri dan automasi perkilangan serta menawarkan alternatif kepada motor putar yang sedia ada. Perkembangan ini dimangkinkan oleh kelebihan-kelebihan yang ditawarkan oleh motor linear seperti saiz dan rekabentuk yang fleksibel, operasi yang bersih dan senyap, penyelengaraan yang mudah serta menawarkan prestasi tinggi untuk aplikasi-aplikasi gerakan linear. Bagaimana pun, halangan utama kepada pereka bentuk sistem untuk menggunakan motor linear dalam aplikasi mereka ialah kos bagi keseluruhan pakej motor linear. Umumnya, motor linear lebih mahal berbanding saingannya disebabkan oleh bilangan magnet kekal dan teknologi penderia yang digunakan bagi sistem penetapan kedudukan.

Motor linear menghasilkan gerakan linear secara terus dan biasanya direka bentuk dengan kepanjangan tertentu yang memerlukan bilangan magnet kekal yang lebih banyak berbanding motor putar. Oleh itu, kos bagi motor linear meningkat mengikut kepanjangan motor itu sendiri. Bagi litar pemandu motor linear yang biasa, penderia kedudukan biasanya digunakan bagi menyediakan isyarat suap balik kedudukan

kepada litar pengawal. Penderia ini agak mahal dan biasanya mempunyai panjang yang sama dengan motor. Harga bagi penderia jenis ini meningkat mengikut saiz, seterusnya meningkatkan harga bagi setiap pakej motor linear.

Bagi sesetengah aplikasi yang tidak memerlukan ketepatan kedudukan seperti pencengkam robot, penderia kedudukan yang mahal dan berketepatan tinggi adalah tidak diperlukan. Tanpa penderia kedudukan ini di dalam sistem akan dapat mengurangkan kos keseluruhan serta menggalakan lebih banyak pembangunan dan aplikasi motor linear. Kajian ini mengkaji dan mencadangkan satu sistem penetapan kedudukan tanpa penderia bagi motor linear DC (LDM). Idea yang digunakan untuk mengawal kedudukan LDM adalah dengan mengawal jumlah arus yang di bekalkan kepada motor. Teknik yang digunakan untuk mengawal arus adalah dengan memanipulasikan isyarat denyut modulasi lebar (PWM). Isyarat PWM ini dihasilkan oleh litar pengawal micro berasaskan pemproses Atmel AVR ATmega8535.

Sebuah model mudah LDM telah dibina bagi tujuan eksperimen. Satu pegas digunakan di dalam reka bentuk motor bagi menyerap daya yang dihasilkan oleh motor. Pemanjangan pegas ini akan digunakan bagi menentukan kedudukan motor. Di sebabkan oleh ayunan harmonik yang berlaku di dalam sistem beban-pegas, kedudukan motor akan berayun sebelum mencapai kedudukan terakhir yang dikehendaki. Untuk membuang kesan ayunan ini, beberapa variasi isyarat PWM akan digunakan untuk menggerakkan motor. Variasi isyarat PWM ini dinamakan sebagai satu fasa, dua fasa, tiga fasa dan empat fasa. Variasi isyarat PWM ini dihasilkan dengan menggabungkan beberapa nilai kitar kerja yang berbeza dan digabungkan di dalam satu isyarat PWM.

Satu model matematik bagi LDM yang dibina telah diterbitkan berasaskan kepada teori ayunan paksa dengan redaman bagi sistem beban-pegas. Persamaan gerakan bagi LDM ini kemudiannya disimulasikan menggunakan perisian Matlab. Berdasarkan kepada hasil simulasi system respon masa, beberapa pengubahsuaian akan dibuat terhadap parameter pemanduan bagi memperbaiki masa naik, peratusan lajakan dan ralat keadaan mantap. Parameter pemanduan yang telah diubahsuai ini kemudiannya akan dipindahkan kepada unit pengawal mikro bagi pelaksanaan eksperimen makmal yang sebenar.

Objektif kajian ini untuk menghasilkan satu sistem penetapan kedudukan tanpa penderia bagi LDM telah berjaya dicapai. Perbandingan yang dibuat ke atas hasil simulasi dan eksperimen sebenar menunjukkan keputusan yang hampir sama. Satu hubungan linear di antara kedudukan motor dan parameter pemasaan yang digunakan di dalam algoritma pengawal telah dikenalpasti dan persamaan linear telah diterbitkan. Persamaan linear ini kemudiannya diterjemahkan ke dalam bahasa pengaturcaraan pengawal mikro sebagai algoritma pengawal suap hadapan. Sebarang kedudukan motor yang dikehendaki boleh dimasukkan ke dalam sistem dan pengawal mikro akan menghasilkan isyarat PWM yang bersesuaian kepada motor. Sistem yang dibangunkan ini boleh digunakan untuk sebarang aplikasi kos rendah yang tidak memerlukan ketepatan kedududukan yang tinggi.

ACKNOWLEDGEMENTS

All praise to supreme almighty Allah swt. the only creator, cherisher, sustainer and efficient assembler of the world and galaxies whose blessings and kindness have enabled the author to accomplish this project successfully.

The author gratefully acknowledges the guidance, advice, support and encouragement he received from his supervisor, Dr. Norhisam Misron who keeps advising and commenting throughout this project until it turns to real success.

Great appreciation is expressed to Dr. Senan Mahmood for his valuable remarks, help advice and encouragement.

Appreciation also to the Faculty of Engineering for providing the facilities and the components required for undertaking this project.

I certify that an Examination Committee met on (February, 12 2008) to conduct the final examination of Ezril Hisham Mat Saat on his Master of Science thesis entitled "A Sensorless Positioning System for Linear DC Motor" 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:

Norman Mariun, Ph.D.
Professor
Faculty of Engineering
University Putra Malaysia
(Chairman)

Ishak Aris, Ph.D.
Associate Professor
Faculty of Engineering
University Putra Malaysia
(Internal Examiner)

Hashim B. Hizam, Ph.D.
Faculty of Engineering
University Putra Malaysia
(Internal Examiner)

____

Hasanah Mohd Ghazali, Ph.D.
Professor/Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

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:

Norhisam Misron, PhD
Lecturer
Faculty of Engineering
University Putra Malaysia
(Chairman)

Senan Mahmood, PhD
Professor
Faculty of Engineering
University Putra Malaysia
(Member)

AINI IDERIS, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 10th July 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.

EZRIL HISHAM MAT SAAT

Date: 1st July 2008

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AC	Alternating Current
DC	Direct Current
FET	Field Effect Transistor
LDM	Linear DC Motor
LIM	Linear Induction Motor
LSM	Linear Stepper Motor
MOSFET	Metal Oxide Semiconductor Field Effect Transistor
PWM	Pulse Width Modulation
EMF	Electromagnetic Field

CHAPTER 1

INTRODUCTION

In recent years, linear motors have been widely used in industry 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 offers high flexibility to the machine in terms of size and space. (Backman (2005)). Few components in motor structure and little lubrication make installation and maintenance easy. Linear motors produce linear motion without using any intermediate mechanical conversion devices. Unlike conventional rotary motor, the absence of intermediate mechanical transmission devices such as gears, belts and motor coupling eliminates backlash and compliance, reducing friction and wears, thus increases motor efficiency (Lee et al. (2000)).

There are many types of linear motors currently available in the market. Commercial linear motor comes in many shapes and sizes, operating principles and electric power sources. The main constraint for system designers to consider linear motor in the design is the cost. Linear motors are expensive, due to the large number of permanent magnets used in the motor and the sensory technologies used in the design. Linear motors provide direct linear motion, thus most of the design of linear motors are in rectangular shape with specific length. Permanent magnets used in the motor normally are mounted on both sides along the rails of the moving coil. The number of permanent magnet increase with the length of the motor which increase the cost for linear motor.

Any electrical motor including linear motor requires special electronic circuit for proper power handling and motion control. These electronic circuits, also known as motor driver or motor controller, are normally designed based on digital signal processors (DSPs) or microcontroller unit (Panahi et al. (1997)). For motor positioning purposes, these digital controllers require position sensors to detect the position of the motor and send feedback signal to the controllers. Typical position sensor for linear motor application includes linear encoders and incremental encoders. Linear encoders measure the relative position of the moving and stationary parts of the drive while incremental encoders measure the changes of position rather than absolute position. These sensors are many times more expensive than typical rotary motor sensor and the price increases with the size or length of the sensor.

The simplest method to control the speed of a DC motor is by controlling its driving voltage. The higher the voltage is the higher speed the motor tries to reach. Speed control of DC motor can be achieved by using variable supply voltage and the direction can be changed by reversing the polarity of the power supply. On the other hands, the torque produced by a DC motor is proportional to the amount of current supply to the motor. The higher the current is the higher torque produced by the motor. Positioning system for motor applications requires motor controller to perform some sort of control algorithms. To obtain precise positioning, the controller normally applies closed-loop control algorithms such as PID controller (Yajima et al. (2001)), Adaptive controller (Zhao and Tan (2004)) and Sliding Mode control (Li and Wikander (2004)). However, for simple and low cost applications which do not require precise positioning, an open loop system can be an alternative.

1.1 PROBLEM STATEMENT

Nowadays, manufacturing industries are looking forward for high speed and high accuracy drives to improve their machines to meet their production demands. Linear motors practically can be used for any applications requiring linear motion and provides solution for industries. However, not all application requires precise positioning such as robot end gripper, electronic locking mechanism and sliding door application. Linear motor used for robot end-gripper is only required to open the end-gripper in horizontal or vertical axis. The tolerance for positioning is not tight, thus high accuracy and expensive linear position sensor is not necessary in such application.

The absence of feedback positioning sensor makes the system an open-loop system. A characteristic of the open-loop system is that it does not use any feedback signal to determine if its input has achieved the desired goal (Choudhury (2005)). Open-loop control is useful for well-defined systems where the relationship between input and the resultant state can be modeled by a mathematical formula. Therefore, mathematical equations describing the system are essential for open-loop system and necessary prior to implementation of the control system. These mathematical equations will be used in early stage for simulation purposes and appropriate adjustment to control algorithms parameters can be made to obtain optimum performance of the system.

1.2 SCOPE OF STUDY

In this research, focus is given on the design and implementation of open-loop feed forward control algorithms for LDM positioning system. The idea to control the position of the motor is by controlling the forces produced by the motor. A basic model of LDM based on design in (Norhisam et al. (2004)) will be constructed with modification and improvement for experimental purposes. A modification is made to the motor by connecting a mechanical spring to the moving coil. The purpose of this mechanical spring is to absorb the forces produced by the motor. Once the forces produced by the motor is equal to the forces absorbed by the spring, the moving coil will stop at some distance. The displacement of the spring then will be used to determine the position of the motor.

The technique used to control the forces produced by the motor is by controlling the current supplied to the coil. In this research, the current control approach is done by manipulating Pulse Width Modulation (PWM) signal through an H-Bridge circuit. The duty cycle of the PWM signal will be used to determine the amount of current flowing to the motor's coil.

The equation of motion for the constructed motor will be derived based on damped force vibration of Mass-Spring system (Malvino (1999)). This equation relates the displacement of the spring and the forces produce by the motor. To observe and study the characteristics of the system, Matlab software will be used to simulate the derived equations. The output of the simulations will be analyzed and appropriate adjustment to the control system parameters will be made to improve the time response of the system.