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UNIVERSITI PUTRA MALAYSIA

DESIGN AND SIMULATION OF A HIGH THRUST LINEAR OSCILLATORY ACTUATOR

ALIAS KHAMIS

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By

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ALIAS KHAMIS

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Chairman: Norhisam Misron, PhD

Faculty: Engineering

An actuator is widely used in many applications either in automation, transportation, productions, robotics, logistics, etc. There are many types of actuator available in the market. An actuator is a device that converts energy into limited mechanical motion. The form of energy could be electric, hydraulic or pneumatic. Electric actuator is much superior compare to other energy form. It gives efficiency, controllability, cost and environmental safety.

This thesis is a study on designing a linear oscillatory actuator based on electromagnetic theory. The aim of this study is to develop a linear oscillatory actuator for mechanical cutter with high thrust. Linear oscillatory actuator (LOA) is a type of linear actuator whereby its motion is in single axis and moves continuously. In this research, the design starts from magnetic analysis using Finite Element Method (FEM). This software can simulate the flux density, flux flow, thrust, cogging force, normal force on the element and material in the motor including electromagnet element. The LOA was designed to have a view of its structure before simulate the design by *Microcal Origin* software. Then, simulation was done to

obtain the best thrust, cogging force and normal force value. Few modifications on the structure are done during this simulation to identify the highest thrust, lowest cogging force and normal force.

Simulations of all designed modelling are compared. Future recommendation has been provided to help other researcher for further development of this LOA.

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

REKABENTUK DAN SIMULASI DAYA TINGGI PENUMATIK AKTUATOR LELURUS

Oleh

ALIAS KHAMIS

Oktober 2007

Pengerusi: **Norhisam Misron, PhD**

Fakulti: **Kejuruteraan**

Aktuator digunakan secara meluas untuk pelbagai jenis aplikasi termasuk automasi, pengangkutan, pengeluaran, robotik, logistik dan lain-lain. Terdapat pelbagai jenis *aktuator* di pasaran. *Aktuator* ialah alat yang menukarkan tenaga tertentu kepada tenaga mekanikal dalam bentuk yang terhad. Tenaga-tenaga ini mugkin elektrik, haudrilik atau penumatik. *Aktuator* elektrik lebih baik berbanding dari jenis lain. Ia memberikan kecekapan yang tinggi, keboleh kawalan, kos yang rendah and selamat untuk alam sekitar.

Kajian ini adalah mengenai penciptaan sebuah penumatik aktuator lelurus berdasarkan teori eletromagnetik. Tujuan kajian ini adalah untuk menghasilkan sebuah aktuator penghayun linear (LOA) untuk pemotong mekanikal dengan daya yang tinggi. Aktuator penghayun linear adalah merupakan salah satu jenis aktuator linear di mana pergerakannya dalam satu paksi dan berterusan. Dalam penyelidikan ini, rekaan bermula dengan analisis magnet menggunakan *Finite Element Method* (FEM). Program ini dapat melakukan simulasi ketumpatan fluk, aruhan fluk, daya, daya *cogging*, daya normal terhadap elemen dan bahan termasuk elemen

elektromagnet. LOA perlulah dilukiskan terlebih dahulu untuk melihat strukturnya sebelum membuat simulasi struktur tersebut menggunakan *Microcal Origin* program. Kemudian, simulasi dijalankan untuk mendapatkan daya yang terbaik, daya *cogging* dan daya normal. Beberapa pengubahsuaian dilakukan pada struktur dalam simulasi untuk mengenal pasti daya yang paling tinggi, daya *cogging* dan daya normal yang paling rendah.

Keputusan secara simulasi bagi semua rekaan dibandingkan. Cadangan untuk projek pada masa akan datang juga dibincangkan untuk membantu para penyelidik membangunkan aktuator elektrik lelurus yang lebih baik.

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I certify that an Examination Committee met on 11th October 2007 to conduct the final examination of Alias Khamis on his Master of Science thesis entitled "Design and Simulation of a High Thrust Linear Oscillatory Actuator" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the student be awarded the relevant degree of Master of Science. Member of the Examination Committee are as follows:

Syed Jabal Javaid Iqbal, PhD
Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Ishak Aris, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Ir. Norman Mariun, PhD
Professor
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Ir. Abdul Halim Mohamed Yatim, PhD
Professor
Faculty of Electrical Engineering
Universiti Teknologi Malaysia
(External Examiner)

HASANAH MOHD. GHAZALI, PhD
Professor and Deputy Dean
School of Graduates Sudies
Universiti Putra Malaysia

Date: 24 October 2007

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

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

Senan Mahmod Bashi, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

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

Date :

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.

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ALIAS KHAMIS

Date: 2 October 2007

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LIST OF ABBREVIATIONS

Nd-Fe-B	Neodymium-Iron-Boron
N	North Pole
S	South Pole
J	Current Density
F	Thrust or Force
N	Number of Turns
I	Current
B	Magnetic Field
ℓ	Length of Coil
d	Displacement
g	Vibration
a	Acceleration
v	Voltage

CHAPTER 1

INTRODUCTION

1.1 Introduction

In this modern day, there are many types of motor available in the market. More special characteristics of motor needed in motor such as high efficiency, small, low weight, produce high thrust and high speed, high precision and others related function. In Malaysia, local industries usually obtain the motor from foreign manufacture. This is due to limited knowledge and technology in the development of the motor [M.Norhisam, 2004].

Basically, rotary motor is always use in industrial application. This rotary motion can be converted to linear motion using belt, gears and screw. For instance, conveyer transports good in a factory. Only two motors can be used instead of a few motor along the conveyer. This method can save cost but for long term, higher maintenance cost and loss of torque due to the use of gear/belt has made it not competitive. Besides, for certain application where high precision position and speed along the conveyer is needed, linear motor is the suitable solution [Syed A. Nasar, 1997].

An actuator is a device that may produce small displacement when in operation. Therefore an actuator can use pneumatic or hydraulic principle to operate. Electrical energy also can be used to operate actuator by using electromagnetic principle. An electric linear electrical actuator is a device that converts electric energy to mechanical motion of limited travel with the help of electromagnetic principle.

Electric actuator is much superior to pneumatic or hydraulic actuator in terms of efficiency, controllability, cost and environmental safety. Nowadays, electricity is available anywhere and even at home.

1.2 Problem Statement

Oil palm motorized cutter introduced by Malaysian Palm Oil Berhad (MPOB) has emerged new era for palm oil industries. It uses 2 stroke petrol engines to supply mechanical energy to a shaft which is bonded with a C shape blade. It has total weight of 6.2 kg and length 3.6 meter. There is a shaft along the rod towards the C shape blade. If the rod length increased, the rod will bend down due to its gravity stability point is out of range. This problem occurred when motorized cutter is used for adult palm oil trees. Adult palm oil trees can achieved 10 meters of height [Abdul Razak J., June 1999].

Therefore, designing an electrical cutter may solve the height problem since only wires and no shaft is required along the rod. Linear actuator is the suitable device which produces small displacement in double axis direction. This actuator will be coupled with a C shape blade. When linear actuator operates, it would make a certain displacement on the C shape blade. This blade will move forward and backward. At high frequency, this C shape blade will only vibrate. This will give smooth cutting shape to the palm. The electric source to the actuator will be supplied by a generator. These projects only focus on the development of the linear actuator.

This linear motor was designed to be used as palm mechanical cutter. It will produce a linear motion where the shaft will move forward and backward. At the end of the shaft, there is a C-curve blade. Therefore, the linear motion will make this C-curve blade to move up and down. First, a study has been conducted in searching any other previous mechanical cutter available in market. Then, linear motor was studied based on the theory to obtain the best design method. It was found that linear motor is suitable for these purposes.

The design starts from magnetic analysis using Finite Element Method (FEM). It is used to solve partial differential equations (PDE) approximately. This software can perform simulation on element and material of the motor. This includes electromagnet element such as flux density, vector, magnetic field etc.

1.3 Aim and Objectives

The aim of this project is to design basic structure of the electric linear actuator for the palm mechanical cutter**.** The objectives of this project are design, simulation and analyze a linear actuator with high thrust for performance study.

The objectives of this study are:

- to propose a basic operation of Linear Oscillatory Actuator for mechanical cutter,
- to design a Linear Oscillatory Actuator,
- to understand the characteristic of Linear Oscillatory Actuator based on the design conducted,

- to compare the characteristics of Linear Oscillatory Actuator based on the simulation findings, and
- to choose the best design of Linear Oscillatory Actuator based on the thrust characteristics findings

1.4 Scope of Work

In this project, the design of linear oscillatory actuator is based on the principles of magnetic circuits. By generating forces to attract the moving yoke periodically on both sides of the yoke, oscillating effect can be produced. Similarly as a linear motor, linear oscillatory actuator movement is small and continuously repeated both ways linearly.

This project can be divided into few stages. The first stage is the study of the basic principal of Linear Oscillatory Actuator (LOA). Once the principal of LOA is understood, the designing stage of LOA can be started. This process is mostly performed on the computer where modelling and Finite Element Method (FEM) simulation software are used. Parameters of the design will be varied in order to obtain the best performance of the motor.

Once this is completed, the next stage is to compare the thrust characteristic based on different design and simulation of the motor. The best performance of thrust characteristic of the motor has been chosen. The motor can be designed for the further development based on the good selection of motor.

After this stage, the performance of the motor has been finalised. From the data obtained, the simulated characteristic of the motor can be obtained.

1.5 Thesis Outline

The first chapter will discuss a brief introduction of the project undertaken here. The aim and objectives has been listed out. Furthermore, this chapter will briefly mention about the outline of the project.

Chapter Two will be discussing about the literature presented. In this chapter, the concept of Linear Oscillatory Actuator (LOA) will be mentioned. The operation wise of the LOA will be explained here. Studies about magnetic theories, magnetic flux and magnetic circuit's concepts will be discussed. The magnetic circuit of the LOA will be discussed along with its representation in electrical circuit terms. The characteristic of the ferromagnetic material used in fabrication will be mentioned briefly.

Methodology of the project will be mentioned in chapter Three. The procedures or steps to complete the project will be discussed in detail. Simulation techniques used will be discussed in this chapter. Then the design of LOA can be finalised. The structure of LOA is produced based on the design. Then the design will be subjected simulated that determine the thrust performance will be discussed.

Chapter Four will present the result and discussion of the comparisons performed. The data of the comparison will be tabulated in this chapter. Explanation of the characteristic based on the simulations result will be discussed.

The last chapter will be the conclusion. All other future suggestions and recommendation are mentioned here. Hopefully all the opinions and ideas will provide benefits for future studies.