Faculty of Electrical Engineering

Design and Development of Linear DC Motor with Constant Thrust For Household Food Processing Application

Siti Zulaika binti Mat Isa

Master of Science in Electrical Engineering

2018

© Universiti Teknikal Malaysia Melaka

DESIGN AND DEVELOPMENT OF LINEAR DC MOTOR WITH CONSTANT THRUST FOR HOUSEHOLD FOOD PROCESSING APPLICATION

SITI ZULAIKA BINTI MAT ISA

A thesis submitted
in fulfillment of the requirements for the degree of Master of Science
in Electrical Engineering

Faculty of Electrical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2018

© Universiti Teknikal Malaysia Melaka

DECLARATION

I declare that this thesis entitled “Design and Development of Linear DC Motor with Constant Thrust for Household Food Processing Application” is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidates of any other degree.

Signature : ……

Name : Siti Zulaika binti Mat Isa

Date : ……..

© Universiti Teknikal Malaysia Melaka

APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in term of scope and quality for the award of Master of Science in Electrical Engineering.

Signature :…….

Supervisor Name : Dr. Raja Nor Firdaus Kashfi Bin Raja Othman

Date :…….

© Universiti Teknikal Malaysia Melaka

DEDICATION

TO MY BELOVED PARENTS

Mat Isa Bin Mohd Zain and Saleha Binti Darus

TO MY BROTHERS AND SISTERS

Mohd Nisizam, Mohd Zawari, Noor Azizah, Noor Idawati and Siti Sari

And lastly to all individuals who always supports all my works without any doubts.

© Universiti Teknikal Malaysia Melaka

ABSTRACT

Nowadays, technologies in food processing applications have grown rapidly to replace the traditional devices. Traditional methods are no longer practical as they require a lot of energy and longer time which will affect the productivity. In the case of tart and samperit, the traditional device has been replaced by modern technology such as the conventional linear DC motor (LDM). Therefore, the conventional LDM could be used to solve issues in traditional devices. Nevertheless, a simple and portable LDM that could produce a constant thrust with longer displacement is required nowadays especially by the small entrepreneurs. Moreover, conventional LDM has another drawback such as only suitable for short displacement. Previously, Typical Linear Actuator (TLA) had been introduced to solve several issues in conventional LDM. Basically, TLA use rotational motor connected to gears and ball screws. However, TLA is not in portable size because the assembly of TLA requires more space to protect the food material from gears, ball screw and grease. Thus, this research proposed a new type of linear DC motor that could produce constant thrust characteristics with longer displacement. The main objective of this research is to propose and analyze new LDM with constant thrust characteristics for food processing application. The modeling involves mathematical calculation using Permeances Analysis Method (PAM) and simulated by Finite Element Method (FEM). There are several parameters in LDM is varied for achieving longer displacement. A prototype of a new LDM is fabricated and measured for result verification. The results show small percentage difference between PAM with FEM and measurement. As a conclusion, this research has provided guidelines for designing LDM with constant thrust capability.

© Universiti Teknikal Malaysia Melaka

ABSTRAK

Pada masa kini, teknologi dalam penggunaan pemprosesan makanan telah berkembang pesat menggantikan peralatan tradisional. Kaedah tradisional tidak lagi sesuai dipraktikkan kerana ianya memerlukan tenaga manusia yang banyak dan memerlukan masa yang lama seterusnya memberi kesan keatas produk tersebut. Dalam kes tart dan samperit, peralatan traditional telah digantikan dengan teknologi moden seperti motor lelurus AT (LDM) yang lazim. Oleh itu, LDM yang lazim juga boleh digunakan untuk menyelesaikan isu-isu berkenaan peralatan tradisional.Walau bagaimanapun, LDM yang ringkas dan mudah alih yang mampu menghasilkan tujahan malar dengan jarak yang lebih jauh diperlukan pada masa kini terutamanya bagi usahawan kecil. Selain itu, LDM yang lazim juga mempunyai kelemahan yang lain kerana hanya sesuai untuk diaplikasikan bagi jarak yang dekat. Sebelum ini, penggerak lelurus biasa (TLA) telah diperkenalkan untuk mengatasi beberapa isu berkaitan LDM yang lazim ini. Kebiasaannya, TLA menggunakan motor berpusing yang dihubungkan kepada gear dan skru bebola. Walau bagaimanapun,TLA bukanlah sejenis yang mudah alih kerana penyambungan TLA memerlukan ruang yang besar untuk melindungi bahan makanan dari gear, skru bebola dan gris. Oleh itu, kajian ini mencadangkan sejenis motor lelurus AT yang dan mampumenghasilkan ciri tujahan malar jarak yang jauh. Tujuan utama kajian ini ialah untuk mencadangkan dan menganalisis LDM yang baru dengan ciri-ciri tujahan malar untuk aplikasi pemprosesan makanan. Model ini melibatkan pengiraan matematik menggunakan kaedah analisis 'Telapan' (PAM) yang akan disimulasi menggunakan kaedah 'Unsur Terhingga' (FEM). Beberapa parameter di dalam LDM telah diubah untuk mendapatkan hasil jarak yang jauh. Prototaip LDM yang baru telah difabrikasi dan dinilai untuk justifikasi keputusannya. Keputusan menunjukkan sedikit perbezaan kadar peratusan antara PAM, FEM dan pengukuran. Kesimpulannya, kajian ini menyediakan garis panduan untuk mereka cipta LDM yang mempunyai kebolehan tujahan malar.

© Universiti Teknikal Malaysia Melaka

ACKNOWLEDGEMENTS

Thanks to Almighty Allah swt. the only creator, cherisher, sustainer and efficient assembler of the world and galaxies who blessing and kindness have enabled this research namely “Modeling and Analysis for Constant Thrust Characteristics Linear DC Motor for Portable Food Processing Application” to be accomplish up to this stage.

Next, I would like to express my highest gratitude to my supervisor Dr. Raja Nor Firdaus Kashfi bin Raja Othman and my co-supervisor Profesor Madya Ir. Dr. Md Nazri bin Othman from Faculty of Electrical Engineering (FKE) Universiti Teknikal Malaysia Melaka (UTeM) for their essential supervisions, supports and encouragements towards completion of my research activity. Thanks to all the knowledge that involve in all aspects which is not limited in the particular area of Electric Machine Design but also in the ethical conducts and social relation aspects as well. And also special thanks to UTeM for financial support throughout this research.

Last but not least thanks to all my peers, my beloved parents; Mat Isa bin Mohd Zain and Saleha binti Darus, and siblings for their endless love and moral support in completing my study. My sincere gratitude also goes to the members of Electrical Machine Design laboratory for their aides, ideas and advices, and my friends who had helped me directly or indirectly.

© Universiti Teknikal Malaysia Melaka

TABLE OF CONTENTS

© Universiti Teknikal Malaysia Melaka

© Universiti Teknikal Malaysia Melaka

LIST OF TABLES

© Universiti Teknikal Malaysia Melaka

LIST OF APPENDICES

© Universiti Teknikal Malaysia Melaka

LIST OF ABBREVIATIONS

LDM	-	Linear DC Motor
SME	-	Small Medium Enterprises
TLA	-	Typical Linear Actuator
DC	-	Direct Current
PAM	-	Permeance Analysis Method
FEM	-	Finite Element Method
LOA	-	Linear Oscillatory Actuator
N	-	North
S	-	South
PLC	-	Programming Logic Controller
NdFeB35	-	Neodymium Iron Boron Magnet
LPMV	-	Linear Permanent Magnet Vernier
PM	-	Permanent Magnet
TF-FRLM	-	Transverse-flux Flux-reversal Linear Motor
emf	-	Electromotive Force
DSTPM	-	double-stator tubular permanent magnet
MMLA	-	Moving Magnet Linear Actuator
HTS	-	High Temperature Superconducting
LRPMA	-	Linear-rotary Permanent Magnet Actuator
LPMM	-	Linear Permanent Magnet Machines

© Universiti Teknikal Malaysia Melaka

LIM	-	Linear Induction Motor
PWM	-	Pulse Width Modulation

© Universiti Teknikal Malaysia Melaka

LIST OF SYMBOLS

x_{op}	-	Operating displacement
Þ	-	Permeance
μ_o	-	Permeability
a	-	Air gap area
l	-	Stack length
θ	-	Angle of stator teeth
g	-	Air gap
r	-	radius
x	-	Displacement
μ_r	-	Relative permeability
g	-	electromagnetic air gap
g_{mc}	-	mechanical air gap
B_r	-	remeance magnetic flux density
H_c	-	coercive force
K point	-	operating point of permanent magnet
B_k	-	operating magnetic flux density of the permanent magnet
$B_{k(n)}$	-	magnetic flux density of coil
n	-	coil
H_k	-	operating coercive force of permanent magnet
A_m	-	area of magnet

© Universiti Teknikal Malaysia Melaka

A_c	-	area of coil
l_c	-	length of coil
ϕ_m	-	flux of permanent magnet
ϕ_c	-	flux of coil
$F_{(n)}$	-	thrust
F_T	-	total thrust
N_c	-	number of turn of coil
I_c	-	current
l_s	-	length of stator
h_s	-	height of stator
g	-	air gap
w_c	-	width of coil
h_c	-	height of coil
g_c	-	gap between coil
l_{pm}	-	length of permanent magnet
h_{pm}	-	height of permanent magnet
l_{my}	-	length of moving yokes
h_{my}	-	height of moving yokes
d_c	-	diameter of the coil
N	-	number of turns
B	-	magnetic flux density
l_e	-	excess length
r_{LOA}	-	Radius of LOA
l_s	-	Length of stator
r_m	-	Thickness of magnet

© Universiti Teknikal Malaysia Melaka

r_s	-	Magnet inner radius
Z	-	value of impedance
θ	-	theta
ω	-	Omega
R	-	resistance
f	-	frequency

© Universiti Teknikal Malaysia Melaka

LIST OF PUBLICATIONS

Journal:

1. R. N. Firdaus, **S. Zulaika**, K. Kamalia, R. Suhairi, M. Z. Aishah, M. N. Othman, A. Khamis, 2016. Design a Slot-less Linear Actuator for Food Processing Application. *Journal of Telecommunication, Electronic and Computer Engineering*, 8(7), pp. 87-91.
2. R.N. Firdaus, **S. Zulaika**, M.Z. Aishah, R.Suhairi, F. Azhar, M. N. Othman, Z. Zakaria, 2017. Modeling and Analysis of Linear DC Motor with Constant Thrust Characteristics. *IEEE Transactions on Industrial Electronics*, pp. 1-7.

Other Publication:

1. R.N. Firdaus, M. Z. Aishah, R. Suhairi, F. Azhar, **S. Zulaika**, M. Othman, 2017. Modelling of Torque and Speed Characterisation of Double Stator Slotted Rotor Brushless DC Motor. *IET Electric Power Applications*, pp. 1–8.
2. R.N. Firdaus, **S. Zulaika**, M.Z. Aishah, M. N. Othman, A. Khamis, F. Azhar R. Suhairi, 2017. Effect of Slot-Width in Slot-Type Linear Motor. *PECON 2016 - 2016 IEEE 6th International Conference on Power and Energy, Conference Proceeding*, pp. 797–801.

© Universiti Teknikal Malaysia Melaka

CHAPTER 1

INTRODUCTION

This chapter gives a brief explanation about the research background of modeling and analysis for constant thrust characteristics of linear DC motor (LDM) for food processing application. It consists of research background, research motivation, problem statement, objectives, contributions and scope of research. Lastly, the description of the content for each chapter is presented.

1.1 Research Background

Malaysia is a well-known nation that rich with variety of culture. In Malaysia, there are many different races exist nowadays but the main are Malay, Chinese and Indian. Each of these races has its own attraction of many aspects in its culture. Culture is a figurative in society based on characteristics and knowledge of particular group of people, encompassing language, religion, cuisine, social habits and music. Focus on Malay races, there are countless symbolic to describe the uniqueness such as festival, cuisine, ethnicity, arts, sports, and architecture (F. Azhar, 2011). For example, during festival there are lots of special things will be found in term of special ritual, islamic tradition, unusual cuisine and others.

Malay ancestry also famous with the traditional cookies especially during Eid Festival. Tart and samperit are the example of traditional cookies as shown in Figure 1.1. These cookies become famous to the entire Asian with its deliciousness. The traditional cookies such as tart and samperit only exist in Malaysia (Zulkifli Hj. Haron, 2012).

© Universiti Teknikal Malaysia Melaka

Because of that, travellers around the world would like to try it when travelling to Malaysia. Currently, samperit and tart are in high demands especially during festivals (Zulkifli Hj. Haron, 2014).

Nowadays especially during Eid Festival, Malay community in Malaysia have no time to make their own cookies like before because there were busy with their hectic lifestyle. They prefer to order or buy the 'ready-made' cookies with the entrepreneurs. This gives an opportunity to entrepreneurs especially in Small Medium Enterprises (SME) to gain more profit at this season. Because of that, the additional production of the tart and samperit is needed to fulfill the requirements of the society.

(a) Samperit (b) Tart

Figure 1.1: The traditional tart cookies.

For over so many years ago, traditional moulding devices have been using by entrepreneurs to produce these cookies (R.N. Firdaus et al., 2016). Figure 1.2 shows the example of the traditional moulding device that has been use by society to produce the tart and samperit. The dough of the samperit and tart is fully filled inside the moulding devices

© Universiti Teknikal Malaysia Melaka

and the external force by human will push the dough inside. The desired shape of tart cookies will come out based on the shape of tart moulding.

Figure 1.2: The tart moulding device.

The demand of the traditional cookies is increasing rapidly especially during Eid Festival. This cause problem and difficulties to entrepreneurs in SME in order to fulfill the requirements of the customers. By using the traditional device, entrepreneurs need to work hard and hire more employees to prepare the customer's order. This will lead to stress, increase the manpower, increase the cost of wages and most of them cannot finish up their work in the given time frame. Traditional devices are no longer practical as it required lots of energy and longer time which will affect the productivity of the cookies.

© Universiti Teknikal Malaysia Melaka

1.2 Research Motivation

Previously, conventional Linear DC Motor (LDM) had been introduced by previous researcher (Mizuno T. et al., 2005) for food processing application which could be used to replace the traditional moulding device. Conventional LDM is a direct contact device that allows the dough to be compressed inside of the LDM itself without compromising the cleanliness factor as shown in Figure 1.3. The proposed motor had been eliminating the ball screw and gears and allows direct contact motion. The conventional LDM also eliminates the rotary motion direct into linear motion.

The design is quiet simple compared with the traditional moulding device, which that the conventional LDM does not require more space which is unlikely of traditional moulding device since it has no external chamber. There are many advantages of conventional LDM compared with traditional moulding device such as it is power equipped device with no external chamber. Besides that, basic structure of the conventional LDM such as mover casing and coil casing is made up from aluminum and plastic respectively.

This is to ensure the cleanliness factor of the dough as it has direct contact with the mover. However, conventional LDM has a few limitations which require improvement for better performance in food processing application such as equipped with moulding or chamber to fill the dough inside it. It is also could only use for short displacement application. Next, there is a Typical Linear Actuator (TLA) that had been proposed by researchers to replace the conventional LDM as shown in Figure 1.4 (Adel.Ismael and Fatih J. Anayi, 2016).

There are many types of TLA with different principle used are exist such as by using hydraulic, pneumatic, gears and etc. Because of that, the proposed TLA can be applied for many applications. The basic concept applied in TLA is compression method

© Universiti Teknikal Malaysia Melaka

which is suitable with the application of food processing. Nevertheless, TLA applying principle of gears which is used rotational motor that connected with gears and ball screws. When the shaft of rotational motor rotates, it rotates the gears and ball screws thus the rod or plunger start to move in translation motion. Basically, TLA applies rotary motion then converts into translation motion.

Unfortunately, the TLA needs assembly with external chamber which shows that the system requires more space even though it protected the food from gear, ball screw and grease. Moreover, TLA is also having few limitations such as it is not practical for simple and portable applications. This will be discussed in next topic.

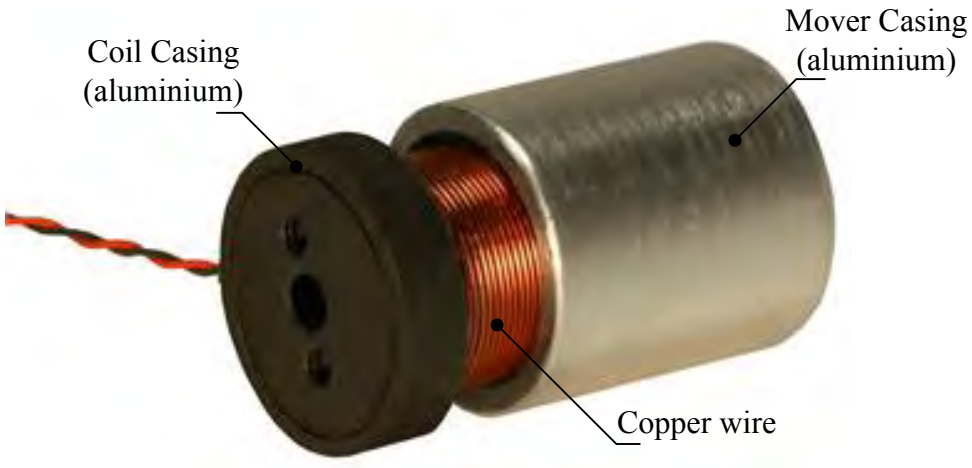

Figure 1.3: Conventional LDM (Mizuno T. et al., 2005).

© Universiti Teknikal Malaysia Melaka

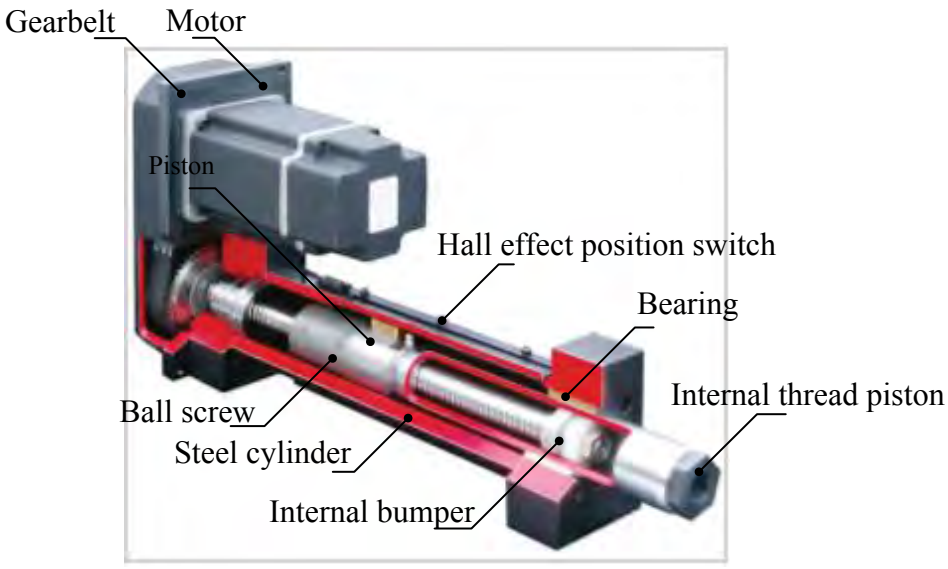

Figure 1.4: Typical Linear Actuator (TLA) (Adel.Ismael and Fatih J. Anayi, 2016).

1.3 Research Problem

The conventional linear DC motor (LDM) had been introduced previously to replace the traditional moulding device but there are also few drawbacks is found such as only can perform for a short displacement (Aoki, A et al., 1998). In addition, it is also not user friendly since it is not in portable size which stated by R.N. Firdaus et al., 2016 in the research entitled design a slot-less linear actuator for food processing application. They also stated the the thrust produce do not fulfill the requirement in food processing application of constant thrust. It should follow the thrust characteristics as shown in Figure 1.5 (R.N. Firdaus et al., 2016).

Besides that, the researchers declare that the operating displacement, x_{op} is the target displacement that should be achieve by the proposed LDM. Basically, x_{op} is the constant displacement of the mover that helps to push the dough inside the chamber. Nowadays, Hussain A. Hussain et al. 2017 state that a simple and portable LDM that could produce a constant thrust with longer displacement is required nowadays especially by the small entrepreneurs. Conventional LDM has a single peak of thrust characteristics over

© Universiti Teknikal Malaysia Melaka