“I hereby declare that I have read through this report entitled “Optimization of Geometric Design of a Linear Type Motion Electrostatic Actuator Using Finite Element Method (FEM)” and found that it has comply the partial fulfilment for awarding the degree of Bachelor of Mechatronics Engineering”

Signature :

Supervisor’s Name : Dr. Mariam Md Binti Ghazaly

Date : 2.6.2016

OPTIMIZATION OF GEOMETRIC DESIGN OF A LINEAR TYPE MOTION ELECTROSTATIC ACTUATOR USING FINITE ELEMENT METHOD (FEM)

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A report submitted in partial fulfilment of the requirements for the degree

of Bachelors of Mechatronics Engineering

Faculty of Electrical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

JUNE 2016

"I declare that this report entitled "Optimization of Geometric Design of a Linear Type Motion Electrostatic Actuator Using Finite Element Method (FEM)" is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree."

Signature	:	
Name	:	Lee Chee Keen
Date	:	2.6.2016

To my beloved father and mother

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ABSTRACT

This research studies on the design and analysis of a linear motion type electrostatic actuator by using Finite Element Method (FEM) with the aid of ANSYS Maxwell 3D version 15.0. The main concern in this research is to analyze the electrostatic characteristics of a linear motion electrostatic actuator as well as geometric characteristics followed by improvements on its efficiency. This simulation software is selected due to its flexibility in simulating force, torque and electric field. Generally, electrostatic actuator is a subtopic under Micro Electro-mechanical System (MEMS) technology which has limited work range as compared to the other MEMS family members. However, its property of being highly sensitive and highly efficiency in microscale has given it a chance to compete with other type of actuators in reality such as implementation in optical display, biomedical and aerospace. However, the main weakness of electrostatic actuator is that, it might require high voltage during actuation with efficient. For this research, the geometric parameters that will affect the actuation are tested and studied which are ratio of electrode-to-spacer of both mover and stator (ES), size of the electrostatic actuator (mm^3) and number of electrodes (n) of both mover and stator. The design of the electrostatic actuator has taken into consideration of three dimensional forces which are actuation force (F_x), shear force (F_y) and attractive force (F_z) as they are relative to each other in simulation result. From the comparison of the simulation results, the geometric modifications during design phase are able to produce high actuation force, low shear force and low attractive force. This is because the force density of the electrostatic actuator can be enhanced by altering its force/volume ratio. Apart from that, the both actuation force and shear force show improvement as the ES ratio of mover and stator increases alongside with the number of electrodes. Yet, the possibility of deformation layer does not show significant reduction although modification was done. For future work, the optimized design can be further improved or developed by undertaking microfabrication under cleanroom environment so that it can be studied and researched perhaps in control system.

ABSTRAK

Penyelidikan ini mengkaji reka bentuk dan analisasi ke atas penggerak elektrostatik yang berjenis linear dengan Kaedah Unsur Terhingga (FEM) dengan bantuan ANSYS Maxwell 3D versi 15.0. Tujuan kajian in adalah untuk mengkaji ciri-ciri elektrostatik dan geometrik penggerak elektrostatik dan seterusnya membuat penambahbaikan pada prestasinya. Perisian simulasi ini dipilih disebabkan oleh fleksibilitinya dalam simulasi yang merangkumi kuat kuasa, tork dan medan elektrik. Secara umumnya, penggerak elektrostatik adalah salah satu subtopik di bawah teknologi Sistem Mikro Elektro-mekanikal (MEMS), di mana kawasan kerjanya adalah terhad berbanding dengan ahli keluarga yang lain di bawah MEMS. Namun, kepekaan dan kecekapan yang tinggi dalam skala mikro telah memberikannya peluang untuk bersaing dengan penggerak berbagai jenis dalam realiti seperti pelaksanaan di paparan optik, bioperubatan dan aeroangkasa. Namun, kelemahan utama penggerak elektrostatik ialah, voltan tinggi mungkin diperlukan untuk bergerak dengan cekap. Dalam kajian ini, parameter geometrik yang akan menjejaskan penggerakan akan diuji and dikaji, iaitu nisbah elektrod ke spacer (ES) oleh penggerak dan pemegun, saiz penggerak elektrostatik (mm^3) dan bilangan elektrod penggerak (n) dan pemegun. jarak ruang udara antara pemegun dan penggerak (d), saiz penggerak elektrostatik dan bahan elektrod. Reka bentuk penggerak elektrostatik telah mengambil kira tiga kuasa-kuasa dimensi, iaitu daya gerakan (F_x), daya ricih (F_y) dan daya menarik (F_z) kerana mereka adalah relatif kepada satu sama lain dalam keputusan simulasi. Perbandingan keputusan simulasi menunjukkan modifikasi geometrik dapat menghasilkan daya gerakann yang tinggi, daya ricih yang rendah dan daya menarik yang rendah disebabkan oleh ketumpatan daya penggerak elektrostatik dapat ditambahbaik dengan mengubah nisbah daya/isipadu. Daya penggerak dan daya ricih bertambahbaik dengan penambahan nisbah ES dan bilangan elektrod. Namun, peratusan deformasi tidak menunjukkan penurunan yang ketara. Langkah seterusnya ialah, reka bentuk yang optimum akan dihasilkan dengan menggunakan teknik mikrofabrikasi yang sesuai.

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MEMS	: Micro Electro-Mechanical System
FEM	: Finite Element Method
ES	: Electrode-to-spacer

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CHAPTER 1

INTRODUCTION

This chapter highlights the background of the research study, problem statement, objectives and the scopes of the project. In this chapter, a brief elucidation on the electrostatic actuator as a member of Micro Electro-mechanical System (MEMS) will be presented. The problem statement dictates the core issue that is to be addressed with this research. Meanwhile, the objectives serve as a benchmark while the scopes define the limits and boundaries of the project in overseeing the project upon completion.

1.1 Background of Study

Micro Electro-mechanical System (MEMS) refers to a technology that utilizes microfabrication technique to develop integrated devices or systems which combine mechanical and electrical components [1,2]. Generally, the feature size of MEMS elements are ranging from micrometers to millimetres [5] which provides an advantage over macroscale devices or system when implemented in various applications such as switches [3,4], sensors [3,5], actuators [3,5], probe [2] and other devices. Being small in size [12], light in weight [12], high sensitivity [12] and highly applicable in high frequency operation [12], MEMS technology is attractive for diverse applications in different fields such as chemical [5], optical displays [1,6], wireless [5] and optical communications [1,3,7], automotive [2], biomedical [3,8] and aerospace [15]. With the advent of micro-scale technology, it has provides a new trend in production for mainly manufacturing sector such as semiconductor manufacturing system [14], machine tools [14] and scanning probe microsystems [14] due to its miniaturized structure [3,7,10], ease of fabrication [3,7,10] and cost effective [3,7,10].

As the continuing improvement on MEMS performance, MEMS devices are highly on demand in the global market nowadays. In general, MEMS devices consist of microsensors [5], microelectronics [5], microstructures [5] and microactuators [5]. Figure 1.1 shows the schematic illustration on MEMS devices.

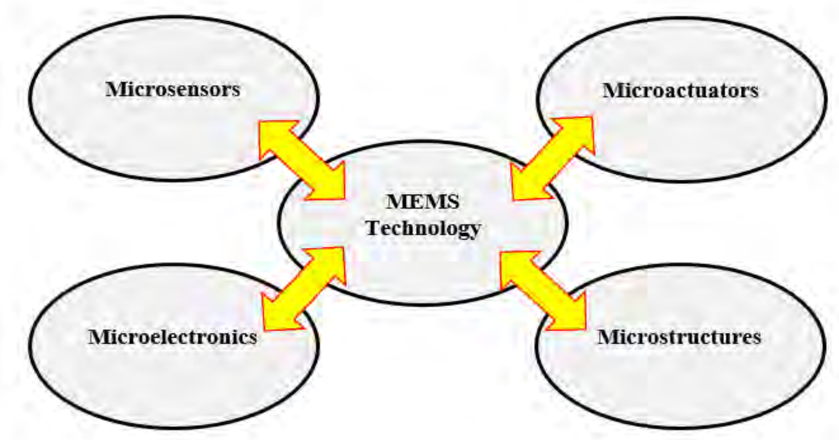

Figure 1.1: Schematic illustration of MEMS devices [5].

In an operation system, the system mechanism is driven by a motor or actuator regardless of its size in either macroscale or microscale structure. Actuator, a type of mechanical device which is responsible for controlling or moving a system or mechanism. Typically, the MEMS actuators are more likely to operate on electrical current than other type of power sources. Generally, microactuators under MEMS technologies operate on 5 types of actuation mechanisms: piezoresistive mechanism [5], piezoelectric mechanism [5], thermal mechanism [5], electromagnetic mechanism [5] and electrostatic mechanism [5]. In comparison, electrostatic actuator is widely used in the field of sensor nowadays due to its high sensitivity property. Apart from that, due to the its small work range compared to other microactuators, it has been limited to only the implementation in simple structure devices such as relay [15], switches [15], valves [15] and displays [15]. Unlike the other 4 microactuators, the large work range of the actuators allows them to be typically used for macroscopic machinery. In term of thrust force, both electrostatic [8] and electromagnetic actuator [5–7] has better performance than piezoelectric actuator [8,9]. In addition, despite of the popularity of electromagnetic actuator amongst the MEMS actuators in the global market, electrostatic actuator is more outstanding than electromagnetic actuator in their heat production and material availability aspect [8]. Yet another advantages of electrostatic actuator is that it has the ability to transmit power without any mechanical contact which has contributed to the simplicity of MEMS system [21].

The concept of electrostatic actuation of a microactuator can be defined as two or more conductors that carry opposite charges, producing changes on capacitive values under supplied voltage. The small changes at the capacitance during motion of the two conductors, mover and stator resulted in high resultant force due to its properties of large-area-to-volume ratio [22]. In comparison, linear motion type electrostatic actuator is more preferable than rotary motion type electrostatic actuator as the research topic since the linear electrostatic actuator has been commercialized for motion control purpose in industrial machinery even though the work range of rotary electrostatic actuator is respectively larger than linear electrostatic actuator.

Although linear electrostatic actuators are mostly used for industrial purpose nowadays, their properties of being miniaturize structured, light in weight, high precision of positioning and cost effective has discovered the potential for further improvement in terms of performance and control system.

1.2 Motivation

As the MEMS devices rises in popularity, the continuing improvement of the electrostatic resultant force which would produce efficient work done has contributed to the development of micromachining technology [23]. In the future, this technology would develop into an important sector in control engineering. However, electrostatic actuation is less popular in selection of engineering system design. In comparison, electromagnetic actuation is most preferable amongst the selection of MEMS technology. For instance, many applications such as card identification and finger print sense application utilize electromagnetic actuation to operate. However, in reality, due to the dispersion of field strength over large area, electromagnetic could not provide accurate positioning as desired.

This scenario has given a chance for electrostatic actuation as it is highly sensitive and accurate actuation in the field of MEMS technology.

In reality, the main constraint of electrostatic actuation is that friction and deformation of layer will occur after period of time which causes a lot of energy lost. This issue has become the problem in producing a good and sustainable actuator under electrostatic actuation. Therefore, the electrostatic force of attraction between mover and stator should be lower to reduce the bending deformation and shear force friction in order to increase the actuation force. The question is, what is the accuracy and efficiency of an electrostatic actuator and what condition is required. The motivation of this research is to solve the problem as mentioned which compare the electrostatic parameters in different considerations. Besides that, FEM analysis is required to tally the development of electrostatic actuator mechanism with the software analysis such that both must meet the minimum requirement especially knowing the loss of energy in the physical medium as compared to no loss simulation.

1.3 Problem Statement

Electrostatic actuators are able to transmit power without mechanical contact during actuation [21]. In fact, it uses hinges in micro to mille scale for its actuation. Generally, electrostatic actuation occurs when there is a motion between two oppositely charged electrodes, mover and stator. In comparison, electromagnetic actuator produces high value of heat compared to electrostatic actuator [8]. However, the work range of electromagnetic actuator as compared to electrostatic actuator is larger. This scenario has provided a research motivation for researchers as there is limited microactuator can operate within small work range [8]. The main concern on the limitation of the electrostatic actuation is that high voltage consuming will produce low actuation force as stated by Coulomb’s Law. According to Coulomb’s Law, the relationship between the input voltage and the electrostatic force or actuation force can be defined as shown in Equation 1.1.

$$F_e = \frac{1}{2}\frac{n\varepsilon_0\varepsilon_r AV^2}{d} \tag{1.1}$$

Where F_e is electrostatic force (N),

n is number of electrode beam,

ε_0 is permittivity of free space (8.854 × 10^{-12} F/m)

ε_r is permittivity of relative material,

A is surface area of each electrode (m^2),

V is voltage supply to electrode (v),

d is distance of air gap between the electrodes (m).

From Equation 1.1, given the other parameters are constant, it is known that the electrostatic force, F_e is directly proportional to V^2. Therefore, the electrostatic parameters of linear electrostatic actuator are analyzed to determine the accuracy and efficiency. As the electrostatic parameters are influenced by the structure of electrostatic actuator, hence, the geometric structure of linear electrostatic actuator is modified, drawn and simulated so as to determine the optimized design for generating high electrostatic force and actuation force while reducing frictional force and possibility of deformation. The variables for altering the geometric design are selected and simulated by using ANSYS Maxwell 3D software with Finite Element Method (FEM) to determine how does the modified structure can be improved or no improved.

Besides that, Finite Element Method (FEM) analysis is rarely been used in the simulation of electrostatic actuator especially for new designs [24]. The development of electrostatic actuator up until today is focusing on comb drive and parallel plate capacitor, which has limited the research boundaries on new designs as there is not much data analysis is taken on new designs within this 5 years or more. As a solution, the FEM analysis on new design has to be proved by comparing the relationship between physical product and FEM simulation. In case the data obtained from both physical product and software simulation are matched, it indicates that the performance of the electrostatic actuator can be further improved in new design. Otherwise, the theoretical assumptions of the electrostatic actuator has to be revised again in the future.

1.4 Objectives of Project

The intention of analyzing data with Finite Element Method (FEM) is to identify the relationship between theoretical analysis and experimental analysis of a linear motion type electrostatic actuator in real world. By considering more than one parameter of electrostatic actuator, it will give an opportunity in choosing the best design to use in various applications. This project embarks to achieve the following objectives upon its completion:

1. To design the linear motion electrostatic actuator varying geometric modification in terms of size, electrode-to-spacer ratio and number of electrode beam of electrostatic actuator.
2. To analyze three dimensional forces based on the geometric modification of linear motion electrostatic actuator.

1.5 Scopes of Project

The research limitation in this project defines the range of data measurements as well as evaluation parameters when conducting the experiments to achieve the objectives as mentioned in previous subchapter. This research is focusing on determining the optimized geometric design of a linear motion type electrostatic actuator. The scopes of the project are established as below:

1. Design a linear motion type electrostatic actuator and its advantages using ANSYS Maxwell 3D software version 15.0.
2. Determine the geometric structure that affect the characteristics of the linear motion type electrostatic actuator.
3. Assign the voltage parameter as input ranging from 0kV to 10kV with step increment of 1kV.
4. Design the linear motion electrostatic actuator varying 6 different sizes which are 5mm × 5mm × 1mm, 10mm × 10mm × 1mm, 15mm × 15mm × 1mm, 20mm × 20mm × 1mm, 25mm × 25mm × 1mm and 30mm × 30mm × 1mm.
5. Design the linear motion electrostatic actuator varying 6 electrode-to-spacer ratio (ES) which are ES= 1:1, ES= 2:1, ES= 3:1, ES= 4:1, ES= 5:1 and ES= 6:1.

6. Design the linear motion electrostatic actuator varying 6 number of electrodes which are n= 5, n=10, n=15, n=20, n=25 and n=30.
7. Offset setting of mover is set to -0.1mm from x-axis.
8. Analyze the designs by using FEM analysis with the aid of ANSYS Maxwell 3D software version 15.0.

1.6 Thesis Documentation Review

The remainder of this research project is organized in term of readability to provide a systematic and elucidate layout for further researches. Chapter 2 provides literature write up based on previous research. Chapter 3 highlights the approaches undertaken in order to realise the objectives of the research. Result alongside with the analysis and discussions are offered in Chapter 4. Finally, yet importantly, a conclusion is drawn from the research and emphasised in Chapter 5. Lists of references and appendices pertaining to the research is attached at the end of the document.

CHAPTER 2

LITERATURE REVIEW

This chapter covers the review of previous works pertaining to the current research. Information necessary for the write up of this section was attained from a collection of books, journals, project papers, articles and reference texts.

2.1 Micro Electro-mechanical System (MEMS)

The phenomenon of highly demand in integrated circuit (IC) devices and system has created a trend for selecting Micro Electro-mechanical System (MEMS) technology for implementing various applications such as sensor [3,5], switches [3,4], actuator [3,5] and relays nowadays. Generally, MEMS technology can be defined as the integrated micro devices or systems which combines electrical and mechanical components [1,2]. In the early implementation of MEMS technology, it has been used with the purpose to sense [1,2], control [1,2] and actuate [1,2] on the micro scale [2,21]. In this era of 21st century, this technology has gradually grows into other areas such as biomedicine [3,8], telecommunications [1,3,7] and optics [1,6]. In general, the size of MEMS components is ranging from 0.01mm to 0.1mm. Basically, there are 5 types of actuators under MEMS technology which are piezoresistive, piezoelectric, thermal, electromagnetic and electrostatic actuator. Figure 2.1 shows the family members of MEMS actuators.