

## الاية

الرَّحْمَنُ الرَّحِيمُ

لَوْ كَانَ الْبَحْرُ مِدَادًا لَّكَلِمَاتِ رَبِّي لَنَفِدَ الْبَحْرُ  
أَن تَنْفَدَ كَلِمَاتُ رَبِّي وَلَوْ جِئْنَا بِمِثْلِ مَدَدِ

صدق الله العظيم

سورة الكهف

## DEDICATION

*The words and measures can never express my deepest gratitude to my parents. They have been a force of strength all along, and without them it would have been an uphill task for me to complete this work.*

*Last but not the least, I am deeply indebted to my brothers, sisters and my friends; their incessant support made me achieve new heights in life and built my character and career.*

## ACKNOWLEDGMENT

In the name of ALLAH, Most Gracious, And Most Merciful Praise is Almighty ALLAH (SubhanahuWata'la) who gave me the courage and patience to carry out this work.

I would like to express my deep gratitude to my supervisor, *Dr. Musaab Zaroug* for his kindness, constant endeavor, guidance and the numerous moments of attention he devoted through this work.

## Abstract

Electrostatic actuators have major role in many MEMS devices, e.g. sensors, actuators. The amount of applied voltage to an electrostatic micro-actuator has a direct impact on the amplitude of deflection throughout the cantilever, as well as the position of the upper electrode has a direct impact on the natural frequency of the micro-actuator.

This research aims to study the amplitude of deflection in a micro-cantilever at different applied voltages as well as different position of the upper electrode and determine the critical points of the applied voltage (pull-in voltage) for different position of the electrode pad on the cantilever at which the amplitude of deflection exceed one-third ( $1\mu\text{m}$ ) of the total gap ( $3\mu\text{m}$ ). Also aims to study the natural frequency for different length of electrode pad that cover the actuator layer. Finite element method, ANSYS was used as a simulation tool.

As a result the range of the applied voltage (pull-in voltage) that caused this cantilever reach the critical point for amplitude of deflection is (32mV-89mV) for different positions of the electrode pad as well as the natural frequency decrease related to increase the upper electrode length.

## المستخلص

للمحرك الكهروستاتيكي دورا هاما في كثير من الانظمة الكهربية الميكانيكية متناهية الصغر على سبيل المثال الحساسات والمحركات، لمقدار فرق الجهد المسلط على المحرك تأثير على مقدار الانحراف للعارض الكابولي، كما ان موضع القطب الكهربائي فوق المحرك تأثير مباشر على التردد الطبيعي .

يهدف هذا البحث لدراسة مقدار الانحراف للعارض الكابولي تحت تأثير قيم مختلفة لفرق الجهد بالإضافة لمواضع مختلفة للقطب الكهربى، وكذلك تحديد الجهود الحرجة المسلطة على القطب الكهربى بمختلف وضعياته على العارض الكابولي وذلك عندما يكون مقدار الانحراف فى العارض الكابولي مساويا لطول الفجوة بين العارض والقاعده، كما انه يهدف لدراسة التردد الطبيعي للعارض الكابولي عندما يكون القطب الكهربى بالكامل على طبقة المحرك.

تم استخدام طرق التحليل المحدود للعناصر ممثله فى (ANSYS (APDL كوسيلة للمحاكاة.

من أهم النتائج وجد أن مدى قيم فرق الجهد المسلط على المحرك الذى يتسبب فى وصول انحراف المحرك الى القيمة الحرجة هو (32mV-89mV) لمختلف الوضعيات للقطب الكهربى، وايضا وجد ان قيم التردد الطبيعي تتناقص بإذدياد طول القطب الكهربى.

# Table of Contents

Number	Contents	page
	الاية	i
	Dedication	ii
	Acknowledgement	iii
	Abstract	iv
	المستخلص	v
	Table of Contents	vi
	List of Figures	vi
	List of Tables	vi
	List of Abbreviations	vi
	<b>CHAPTER ONE : Introduction</b>	<b>1</b>
1.1	Research problem	1
1.2	Aims and Objectives	1
1.3	Literature review	1
1.3.1	Materials & Methods	3
1.3.2	Conclusions	7
1.4	Research Methodology	7
	<b>CHAPTER TWO: Theoretical Background</b>	<b>8</b>
2.1	Introduction to MEMS	8
2.2	Materials and Fabrication Techniques for MEMS	10
2.2.1	Introduction	10
2.2.2	Materials	11
2.2.2.1	Substrates	11
A	Silicon	11
B	Quartz and Glasses	11
2.2.2.2	Additive Materials	11
2.2.3	Fabrication Techniques	12
2.3	MEMS Devices and Applications	12
2.4	Actuators and Actuation	13
2.4.1	Electrical Micro-actuators	14
2.4.2	Electrostatic Actuation	14
2.4.2.1	Electrostatic Gaps	17
2.4.2.2	Parallel-Plate Capacitor	18
2.5	The Cantilever Beam MEMS Resonator	22
2.5.1	Cantilever Beam Design Requirements	22
2.5.2	Electrostatic Coupling of MEMS Resonators	23

2.5.3	Resonator Specifications	23
2.6	ANSYS	24
	<b>CHAPTER THREE: Electrostatic Actuator Design</b>	<b>25</b>
3.1	Introduction	25
3.1.1	Base layer	25
3.1.2	Isolator layer	25
3.1.3	Actuator layer	26
3.1.4	Pad layer	26
3.2	Programming	26
3.2.1	Pre-process	26
3.2.1.1	Element type	26
3.2.1.2	Material properties Defining	26
3.2.1.3	Geometry	27
3.2.1.4	Mesh	28
3.2.2	Solution	29
A	Analysis Type	29
B	Load Definition	29
C	Solve	30
3.2.3	Post process	30
3.3	Effect of the Electrode Position on the Natural Frequency	31
3.3.1	Natural frequency by analytical methods for 100% of cantilever covered with electrode pad: (L=200 $\mu$ m)	32
3.3.2	Natural frequency by analytical methods when (L=180 $\mu$ m)	33
3.3.3	Natural frequency by analytical methods when (L=160 $\mu$ m)	34
3.3.4	Natural frequency by analytical methods when (L=140 $\mu$ m)	35
3.3.5	Natural frequency by analytical methods when (L=120 $\mu$ m)	36
3.3.6	Natural frequency by analytical methods when (L=100 $\mu$ m)	37
3.3.7	Natural frequency by analytical methods when (L=80 $\mu$ m)	38
3.4	Natural frequency Simulation Results	39
	<b>CHAPTER FOUR: Results &amp; Discussions</b>	<b>40</b>
4.1	Introduction	40
4.2	Effect of an Applying voltage and Electrode position on the amplitude of deflection	40

4.2.1	Electrical Potential and Amplitude of deflection under Applied voltage (32 mV) when 100% of cantilever covered with electrode pad	40
4.2.2	Electrical Potential and Amplitude of deflection under Applied voltage (33 mV) when 90% of cantilever covered with electrode pad	42
4.2.3	Electrical Potential and Amplitude of deflection under applied voltage (35 mV) when (L=160 $\mu$ m)	43
4.2.4	Electrical Potential and Amplitude of deflection under applied voltage (38 mV) when (L=140 $\mu$ m)	44
4.2.5	Electrical Potential and Amplitude of deflection under applied voltage (40 mV) when (L=120 $\mu$ m)	45
4.2.6	Electrical Potential and Amplitude of deflection under applied voltage (43 mV) (L=100 $\mu$ m)	46
4.2.7	Electrical Potential and Amplitude of deflection under applied voltage (47 mV) when (L=80 $\mu$ m)	47
4.2.8	Electrical Potential and Amplitude of deflection under applied voltage (55 mV) when (L=60 $\mu$ m)	48
4.2.9	Electrical Potential and Amplitude of deflection under applied voltage (65 mV) when (L=40 $\mu$ m)	49
4.2.10	Electrical Potential and Amplitude of deflection under applied voltage (89 mV) when (L=20 $\mu$ m)	50
4.3	Amplitude of deflection Simulation Results	51
4.4	Charts	52
4.4.1	Relationship between Electrode Position and Natural Frequency	52
4.4.2	Relationship between Voltage and Amplitude of deflection at 100% of Cantilever covered with Electrode Pad	53
4.4.3	Relationship between Voltage and Amplitude of deflection at 90% of Cantilever covered with Electrode Pad	54
4.4.4	Relationship between Voltage and Amplitude of deflection at 80% of Cantilever covered with Electrode Pad	55
4.4.5	Relationship between Voltage and Amplitude of deflection at 70% of Cantilever covered with Electrode Pad	56
4.4.6	Relationship between Voltage and Amplitude of deflection at 60% of Cantilever covered with Electrode Pad	57



4.4.7	Relationship between Voltage and Amplitude of deflection at 50% of Cantilever covered with Electrode Pad	58
4.4.8	Relationship between Voltage and Amplitude of deflection at 40% of Cantilever covered with Electrode Pad	69
4.4.9	Relationship between Voltage and Amplitude of deflection at 30% of Cantilever covered with Electrode Pad	60
4.4.10	Relationship between Voltage and Amplitude of deflection at 20% of Cantilever covered with Electrode Pad	61
4.4.11	Relationship between Voltage and Amplitude of deflection at 10% of Cantilever covered with Electrode Pad	62
	<b>CHAPTER FIVE: Conclusion &amp; Recommendations</b>	63
5.1	Conclusion	63
5.2	Recommendations	64
	References	65

## List of Figures

Figure	Title	page
(1.1)	:the lower electrode at the beam free-end figure (b) :the lower electrode close to the beam anchorfigure(c)	4
(1.2)	A single degree of freedom model	5
(2.1)	parallel-plate capacitor	18
(2.2)	Cantilever Beam	20
(2.3)	cantilever beam as a parallel-plate capacitor whose top plate experiences a distributed force	21
(3.1)	Drawn geometry	28
(3.2)	Mesh	29
(3.3)	Geometry with Applied load	30
(3.4)	Natural frequency by ANSYS for(L=200 $\mu$ m)	32
(3.5)	Natural frequency by ANSYS for(L=180 $\mu$ m)	33
(3.6)	Natural frequency by ANSYS for(L=160 $\mu$ m)	34
(3.7)	Natural frequency by ANSYS for(L=140 $\mu$ m)	35
(3.8)	Natural frequency by ANSYS for(L=120 $\mu$ m)	36
(3.9)	Natural frequency by ANSYS for(L=100 $\mu$ m)	37
(3.10)	Natural frequency by ANSYS for(L=80 $\mu$ m)	38
(4.1)	Electrical Potential and Amplitude of deflection under Applied voltage (32 mV)for 100% covered	40
(4.2)	Electrical Potential and Amplitude of deflection under Applied voltage (33 mV)for 90% covered	42
(4.3)	Electrical Potential and Amplitude of deflection under Applied voltage (35 mV)for 80% covered	43
(4.4)	Electrical Potential and Amplitude of deflection under Applied voltage (38 mV)for 70% covered	44
(4.5)	Electrical Potential and Amplitude of deflection under Applied voltage (40 mV)for 60% covered	45
(4.6)	Electrical Potential and Amplitude of deflection under Applied voltage (43 mV)for 50% covered	46
(4.7)	Electrical Potential and Amplitude of deflection under Applied voltage (47 mV)for 40% covered	47
(4.8)	Electrical Potential and Amplitude of deflection under Applied voltage (55 mV)for 30% covered	48
(4.9)	Electrical Potential and Amplitude of deflection under Applied voltage (65 mV)for 20% covered	49
(4.10)	Electrical Potential and Amplitude of deflection under Applied voltage (89 mV)for 10% covered	50

(4.11)	Relationship between Electrode Position and Natural Frequency	52
(4.12)	Voltage VS Amplitude of deflection at 100% of Cantilever covered with Electrode Pad	53
(4.13)	Voltage VS Amplitude of deflection at 90% of Cantilever covered with Electrode Pad	54
(4.14)	Voltage VS Amplitude of deflection at 80% of Cantilever covered with Electrode Pad	55
(4.15)	Voltage VS Amplitude of deflection at 70% of Cantilever covered with Electrode Pad	56
(4.16)	Voltage VS Amplitude of deflection at 60% of Cantilever covered with Electrode Pad	57
(4.17)	Voltage VS Amplitude of deflection at 50% of Cantilever covered with Electrode Pad	58
(4.18)	Voltage VS Amplitude of deflection at 40% of Cantilever covered with Electrode Pad	59
(4.19)	Voltage VS Amplitude of deflection at 30% of Cantilever covered with Electrode Pad	60
(4.20)	Voltage VS Amplitude of deflection at 20% of Cantilever covered with Electrode Pad	61
(4.21)	Voltage VS Amplitude of deflection at 10% of Cantilever covered with Electrode Pad	62

## List of Tables

<b>Table</b>	<b>Title</b>	<b>Page</b>
(2.1)	MEMS Devices and Applications	13
(3.1)	Material properties in $\mu$ MKSV units	27
(3.2)	Natural frequency result	39
(4.1)	Amplitude of deflection Simulation Results	51

## List of Abbreviations

MEMS	Micro-Electro-Mechanical System
FEM	Finite Element Method
ANSYS	Analysis System
FEA	Finite Element Analysis
NT	New Technology
TE	transverse electric
SRR	split ring resonator
VLSI	very large-scale integration
IC	integrated circuit
MST	Microsystems technology
LIGA	the German acronym for Lithographie, Galvansformung, Abformung
DMD	digital mirror display
APDL	ANSYS Parametric Design Language