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DESIGN AND ANALYSIS OF BIO INSPIRED CANTILEVER MICRO GRIPPER NEEDLE FOR SURGICAL APPLICATIONS

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ABSTRACT

Microelectronics Mechanical systems (MEMS) are the class of the miniature device that are fabricated based on micro machined process. These devices are having 100 to 1000 µm dimension in range. MEMS technology is a combination of Electronic function and Mechanical in structure also preferred in every segment of medical device function due to its flexibility and multidimensional in its nature. Most of the Miniaturized sensors and actuators used in the surgical applications give a wide accuracy and efficiency. The Research proposal describes the functionality and performance of cantilever model micro gripper used in medical and surgical applications to measure the resonant frequency and its harmonic oscillations under different conditions of strain. Micro gripper based cantilever MEMS model is analyzed by selection of materials, device dimensions, process parameters modelling. Different test conditions of micro gripper's Functionality and performance is evaluated.

Keywords: MEMS, cantilever, micro gripper, Eigen frequencies, mesh.

1. INTRODUCTION

Due to wide acceptance and rapid technology growth development and multidisciplinary MEMS domains, leads to high accuracy in performance, low weight, small size, easy mass-production and low cost. Some applications of MEMS in various fields such as Mechanical, Microfluidics, RF MEMS, Optical MEMS also the latest developments in all branches of engineering domains [1]. MEMS has speared all over the consumer electronic appliances and also other area such as home, automotive, aerospace, biomedical, recreation and sports etc. The is divided into six Parts. First part of the study describes the Introduction. Second part explains characterization and functionality of MEMS with sensing techniques, Designing of cantilever and its functionality in third part. fourth part designates the functionality of Micro gripper acts as bio-inspired robotic finger for gripping the blood cells and effected tissues and so on. Characterization of MEMS sensors acts as micro gripper explained in part five. Finally, in part six, analysis is made with different characteristics of cantilever based micro gripper during surgical procedure by analysing resonant frequency and harmonics oscillations [2] with applications.

1.1 MEMS Characterization

MEMS devices and its structures are characterized to evaluate properties of materials changing at micro-scale due to grain boundary effect. Re design and manufacturing needed to have reliable knowledge on properties of materials. Verification and validation of the designed models to measure the calibration and conditions of the signals. MEMS refers to microfabrication on lab-on-a-chip to measure mechanical properties Young's modulus to Maintain the Integrity of the Specifications and functionality [2].

1.2 MEMS Functionality

MEMS sensor is combination of miniaturized in structure with sensors and actuators with an integral part of electronics. The important parts in the devices are micro-sensors and micro-actuators. These are categeorized into sensors and transducers. The sensors collect information and converts into mechanical signal actuators act and produce mechanical function upon the signal that is received. In case of micro-sensors [3], the device converts a measured mechanical quantity into an electrical information and fabrication using device micro matching process.

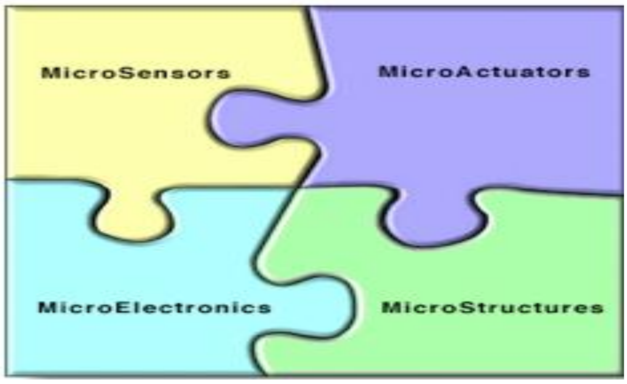

Figure-1. MEMS device components.

Micro machining is a process of combining and creating a 3D micro components using silicon as the primary material. To produce a variety of 3D micro components sheets of metal or slices of silicon is used.

2. DESIGNING OF CANTILEVER AND ITS FUNCTIONALITY

A cantilever is a beam supported by one end. "The beam transports the load to support and resisted by moment and stress. Cantilever construction allow to change the structures without external bracing. Cantilever beams are universal structures in the field of microelectromechanical systems" [5]. MEMS cantilevers are usually fabricated from silicon (Si), silicon nitride

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(SiN), or polymers. Fabrication process involves weakening/under cutting cantilever structure to make fluctuations usually with an anisotropic wet or dry etching technique. A large group of researchers are working to develop a cantilever array working as biosensors for medical diagnostics and its applications [4]. Some of the other applications of MEMS cantilevers such radio frequency filters and resonators. In this article, MEMS cantilever acts as Sensor in RF application" [6].

Single Degree of Freedom is represented by simple system consisting of a mass and a spring

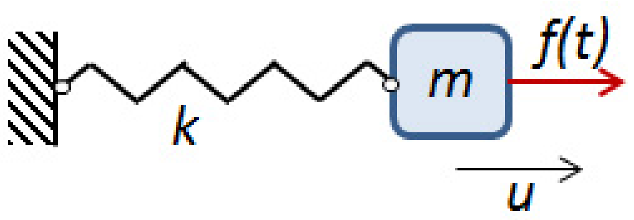

Figure-2. Single degree of Undamped system.

mii+ku=f(t) (1)

where $u=A\sin\omega_0 t+B\cos\omega_0 t$

and
$\omega_0=\sqrt{k/m}$
(2)

ω_0 *is* angular frequency and unit is rad/s and related to natural frequency is

$\omega_0=2\prod f_0.\ \omega_0$ (3)

Eigenfrequency expression exhibits a function and represents how stiffness and mass influence eigenfrequencies: damping in the system, then the equation

$\omega 0 \propto \sqrt{\text{stiffness / inetia}}$ (4)

Where $\omega 0$ is kinetic energy of mass, that is transformed into strain energy of spring, and vice versa. viscous damping of system equation

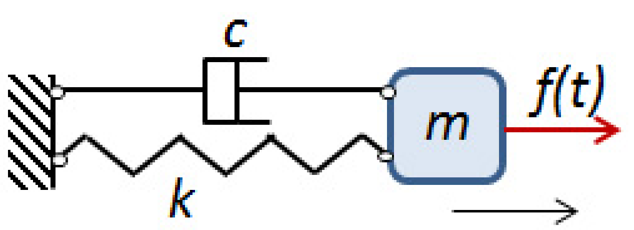

Figure-3. Viscous damping oscillations of system.

mu+cu+ku=f(t) (5)

It is convenient to employ a complex notation of a system in order to analyze the harmonics represented by $e^{j\omega t}$. Displacement is written as $\mu = \mu e^{j\omega t}$. Where μ is complex amplitude, In absence of external forces $(\omega 2m+i\omega c+k)\mu^{i\omega t}=0$ this equation is applicable only for a value of ω, and when μ not equal to 0 and is given by-

$\omega 2+i\omega c/m+k/m=0$ and $\omega 0=k/m$ and $\zeta=c/2\sqrt{km}$ (6)

Therefore,
eigenvalue equation becomes

$-\omega 2+2\omega\varsigma\omega_0\,\omega+-\omega_0 2=0$ (7)

Where
ω undamped angular or natural frequency and repredented by damping ratio.

Multiple Degrees of Freedom linear multiple degrees of freedom system characterized by a matrix equation

Mu + Cu + Ku = f(t) (8)

where is the M is mass matrix, C is damping matrix, and K is stiffness matrix The DOFs are placed in the row vector u and forces in f(t).
free vibration problem can be describing by complex eigen vakue equation (9)

$(-\omega 2M+i\omega c+k)\,\mu e^{i\omega t}=0$ (9)

and finally eigenvalues can be finding by

$\det(-\omega 2M+i\omega c+k)\,\mu e^{i\omega t}=0$ (10)

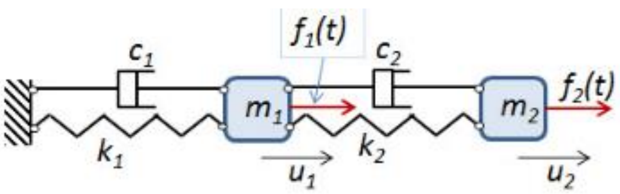

Figure-4. Two stage degree of freedom system.

2.1 Design for MEMS based Cantilever

Prototype of MEMS based Cantilever is included in the designs Therefore, the focus here to use cantilever as sensor and micro gripper. MEMS acts as resonator for high range of applications. The parameters include here are spring constant and resonant frequency. Spring constant is prime factor to design and verify variable resonant frequencies. This section will discuss some of the parameters to use the cantilevers [8] acts as MEMS Micro-cantilever robotic micro gripper. Grasping of small and micro objects is critical especially in surgical, medical and also biological and others applications. Cantilever beam is fixed [10] at one end and free on other end. Load carried by beam to support by the moment and stress. The moment of cantilever deflects by Appling a force at the other end. The design aspect includes length of the cantilever is must be greater than the width and its optimum thickness [11-12]. The table 1 explains the

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characterization and material properties of Cantilever based robotic gripper finger.

3. BIO INSPIRED CANTILEVER MICRO GRIPPER ROBOTIC FINGER

The prime key parameters involved in Stoney's formula related to cantilever end deflection δ is represented in equation (11)

$$\delta=(3\sigma(1-v)/E)*(L/t)2 \quad (11)$$

where ν is Poisson's ratio, E is Young's modulus, L is the length of beam and t is the thickness of cantilever. Capacitive and optical methods have been used to measure the change in static deflection. The another formula relating to spring constant k and its dimensions and material constants as indicated in the equation (12).

$k=qdc / Ymax$ (12)

where qdc is the load distributed uniformly over a beam length, the challenge lies in their practical application used either square or cube that dependences on cantilever size [7], specifications on its dimensions. Most importantly the cantilevers are sensitive to micro variations by its process parameters. Finally, the prime advantage of MEMS based cantilevers is cheap in cost by fabrication in large arrays.

Table-1. Characterization and material properties of Cantilever of Silicon as MEMS material.

Material
Label: Silicon 2
Material Properties
Material Contents

Property	Name	Value	Unit	Property group
Relative permeability	mur	1	1	Basic
Electrical conductivity	sigma	1e-12[S/m]	S/m	Basic
Coefficient of thermal expansion	alpha	2.6e-6[1/K]	1/K	Basic
Heat capacity at constant pressure	Cp	700[J/(kg*...	J/(kg·K)	Basic
Relative permittivity	epsilonr	11.7	1	Basic
Density	rho	2329[kg/...	kg/m³	Basic
Thermal conductivity	k	130[W/(m...	W/(m·K)	Basic
Young's modulus	E	170e9[Pa]	Pa	Young's modulus and Poisson...
Poisson's ratio	nu	0.28	1	Young's modulus and Poisson...
Refractive index, real part	n	3.48	1	Refractive index
Refractive index, imaginary part	ki	0	1	Refractive index

4. CHARACTERIZATION OF MEMS SENSORS ACTS AS MICRO GRIPPER

Functionality of Micro gripper cantilever based MEMS sensor is evaluated based on resonant Eigen frequency and finding the harmonic oscillations across it. Design analysis of micro gripper for different Eigen resonant frequencies are indicated at different models.

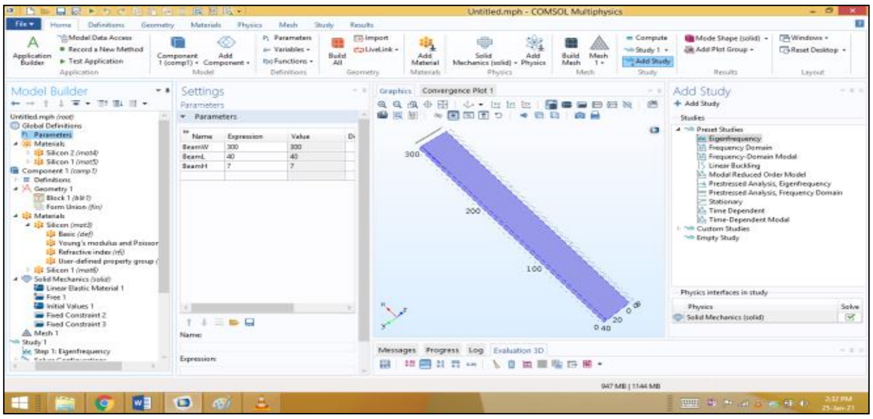

Figure-5. Device dimensions of beam width, length and height.

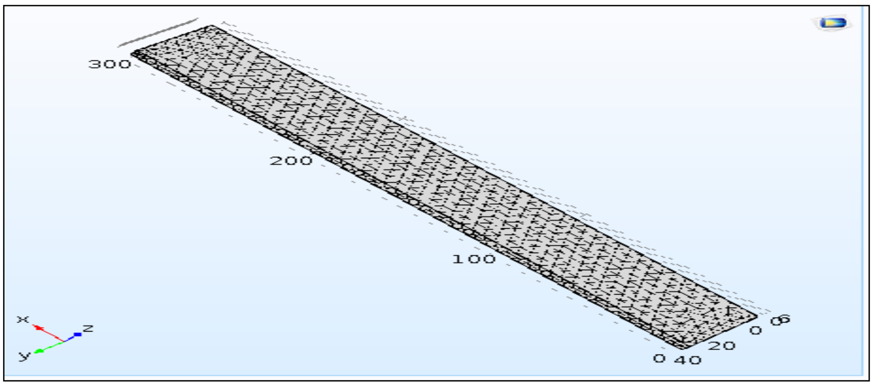

Figure-6. Physical analysis with extra fine meshing.

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Charactization of Polysilicon material is analyxed with finetunning by meshing the catileverbeam

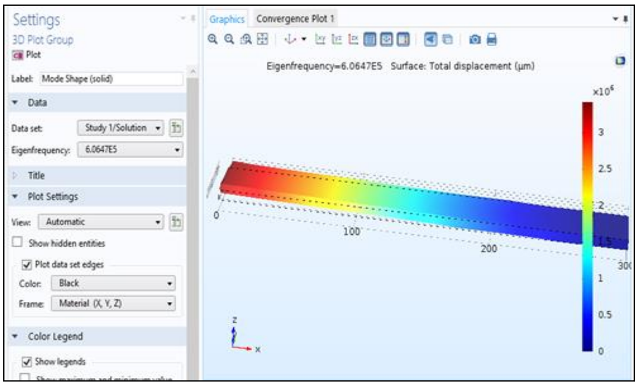


Figure-7. Eigen frequency of 1.0814E5.

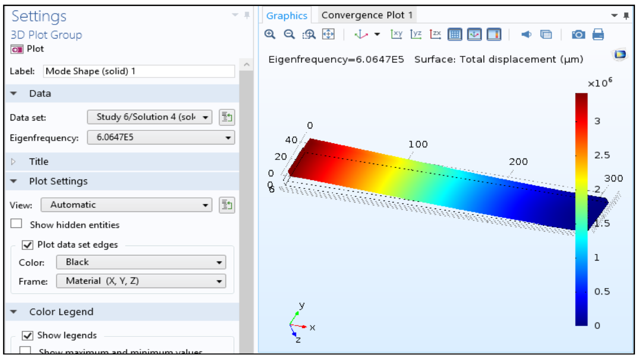


Figure-8. Eigen frequency of 6.066E5.

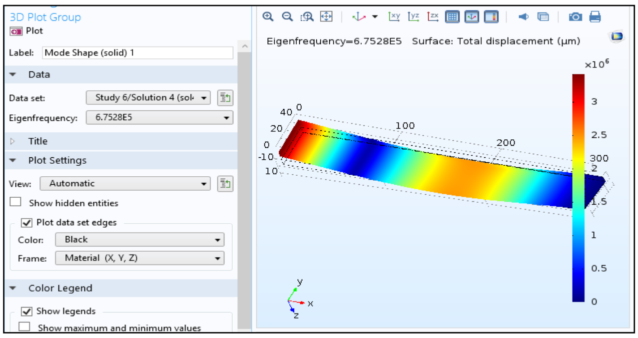


Figure-9. Eigenfrequency of 6.7607E5.

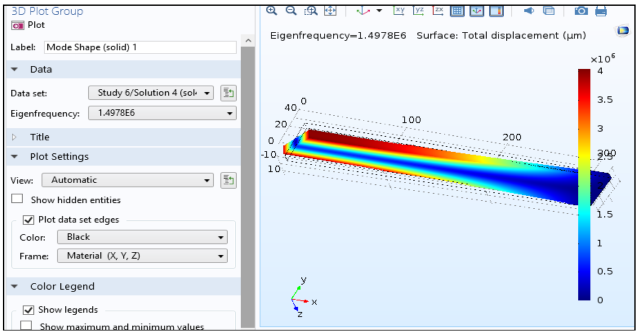


Figure-10. Eigen frequency of 1.5115E6.

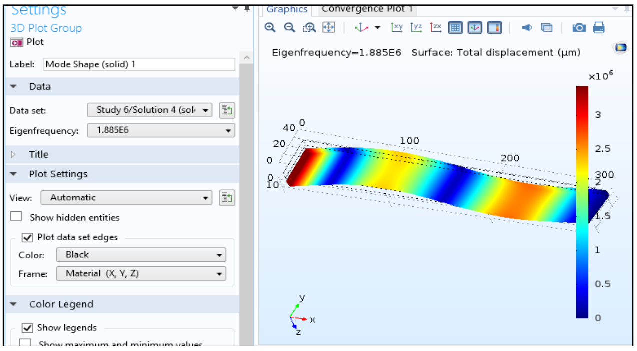


Figure-11. Eigen frequency of 1.8883E6.

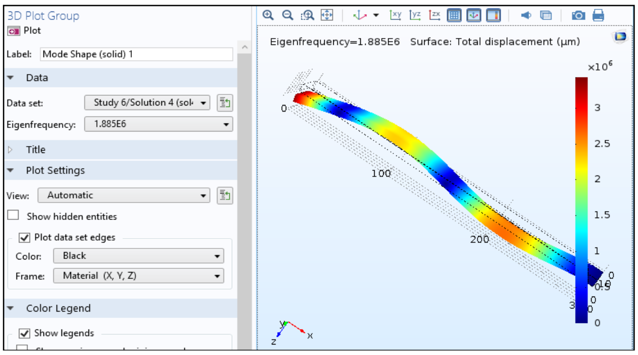
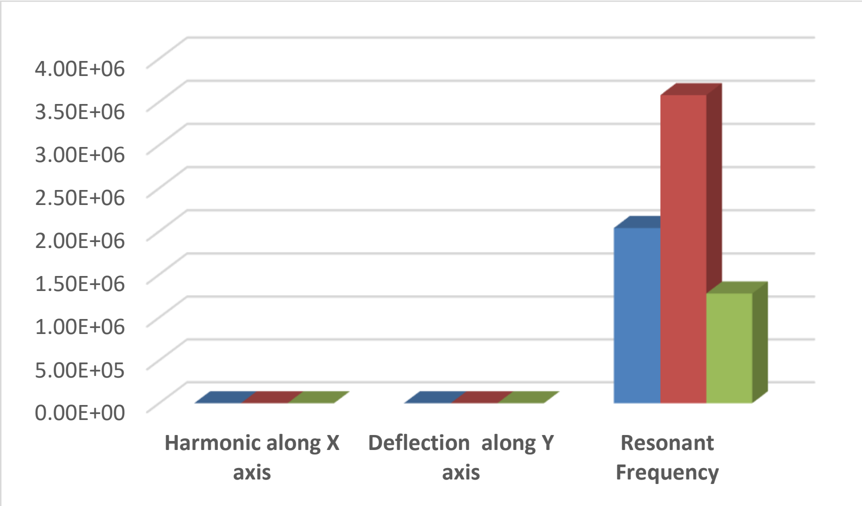


Figure-12. Eigen frequency of 3.5323E6.

5. ANALYSIS OF RESONANT FREQUENCY AND HARMONICS

Table-2. Harmonic distortions, deflection with intensity of oscillation in Three dimensional.

Harmonic along X axis	Deflection along Y axis	Resonant Frequency along Z axis
3.8474E0	8.3712E0	2.0387E6
8.6506E1	3.8614E1	3.5772E6
2.5555E1	1.9713E1	1.2796E6



For a minimum amount of Harmonics and deflections along x and y axis, there is a possibility of getting maximum resonant
Frequency along Z-axis

5.1 Report on Deflection with Intensity

COMSOL 5.2.0.166 has geometry in 1 domain, 6 boundaries, 12 edges, and 8 vertices.

Mesh contains of 1608 domain elements, 1224 boundary elements, and 172 edge elements.

Mesh consists of 5401 domain elements, 2140 boundary elements, and 244 edge elements.

Degrees of freedom of 28404.Solution and time: 13 s. mesh consists of 1608 domain elements, 1224 boundary elements, and 172 edge elements. Number of degrees of freedom solved for: 10365. and time: 10 s.

6. CONCLUSIONS

Miniaturized Micro Gripper based cantilever has a flexibility of changing the characteristics and harmonics by varying the resonant Eigen frequency. Designing of Bio-inspired robotic micro gripper cantilever approach leads to higher accuracy and efficiency. Such devices are mostly used in surgical applications in order to analyze the characteristics and repair cell and small parts of tissues, nerve, microbes in microsurgery and measurements. The Martial silicon used in the research has specific constraints and these constraints change for other parameters. These specific physical electrical and mechanical characteristics are expected in three dimensional structure by deflection sensitivity and intensity thereby considering its boundaries, edges, and vertices.

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