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Modeling and Simulation of Micro-Electromagnetic Actuator

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***Abstract*— MEMS (Micro Electro Mechanical System) is technology of combining electronics and mechanical components integrated on chip to produce micron scale devices. MEMS can sense, process, actuate, compute and also communicate. The miniaturized system have better response time, faster analysis and diagnosis, good statistical results, improved automation possibilities with decreased risk and cost. The objective of this work is to model and simulate micro electromagnetic actuator driven by the electric current in the coil. The process of generating a magnetic flux (and hence force) by means of an electric current flowing through the coil can be called as electromagnetic excitation. Because of this force cantilever beam gets deflected. The work focuses on electromagnetic actuator modeling and simulation. Electromagnetic actuator has been modeled and simulated using COMSOL Metaphysics software.**

***Keywords* - Micro actuation, Electromagnetic actuator, Modeling and simulation, micro systems.**

I. INTRODUCTION

A technology that considers manufacturing of micron scale, sensors actuators and systems similar to semiconductor chip is referred to as micro electromechanical systems, or MEMS [1]. MEMS have been identified as one of the most promising technologies for the 21st century and have the potential to revolutionize both industrial and consumer products by combining silicon based microelectronics with micromachining technology [2]. MEMS are attractive for many applications because of their small size, weight, and power consumption, which allow systems to be miniaturized [3]. The electromagnetic force plays a major role in determining the internal properties of most objects encountered in daily life. The work focuses on principle based on electromagnetic technique to actuate the cantilever beam [4,5]. The applications of magnetic actuators are many including microsurgery, optical switching, data writing and reading [1]. The proposed work is modeled and simulated in COMSOL/Multiphysics. By selecting space dimension as 3D, physics as magnetic fields and solid mechanics and study as stationary and time dependent. The parameters like magnetic flux density, electromagnetic force and displacement of micro electromagnetic actuator without core is compared with micro electromagnetic actuator with core.

A) Electromagnetic actuator without core

The excitation source is an ac current of frequency 100Hz and 1A flowing into the windings. The coil is composed of few number turns of copper wire wounded with diameter and length of coil assembly is 10µm and 80µm respectively. Solenoid used as coil which generates a time varying magnetic field which induces eddy currents. The interaction between the eddy current and magnetic field causes electromagnetic force on the micro cantilever [6]. This force acts on cantilever beam into deflection.

A) Electromagnetic actuator with core

The schematic diagram of the excitation principle of the electromagnetic actuator with core is shown in Fig.1

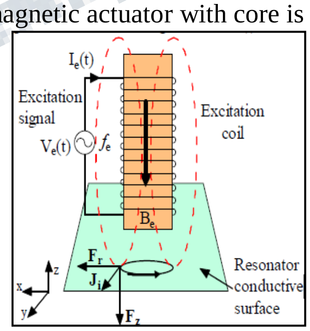

Fig.1 Schematic diagram of the electromagnetic actuator with core

The operation is same as that of electromagnetic actuator without core. Current carrying solenoid behaves like a bar magnet, if we place a soft iron rod (core) inside the solenoid, the magnetism of the solenoid increases by about hundred times and the solenoid is called an 'electromagnet'. It is temporary magnet [7]. An electromagnet is made by winding closely a number of turns of insulated copper wire over a soft iron rod. On passing current through this solenoid, a magnetic field is produced in the space within the solenoid.

II. THEORETICAL BACKGROUND

A right hand thumb rule is used to determine the direction of magnetic field around a conductor carrying current [8]. It states that, hold the current carrying conductor in the right hand such that the thumb pointing in the direction of current and parallel to the conductor, then curled fingers point in the direction of the magnetic lines of flux around it. The total magnetic lines of force i.e. magnetic flux crossing a unit area in a plane at right angles to the direction of flux is called magnetic flux density. It is denoted by B, and is measured in Tesla.

a. *Magnetic field on the axis of circular coil*

The current carrying coil of circular loop has radius r. Current in the loop is I. Then the magnetic flux density in Tesla is given by

$$B=\frac{\mu_0 Ni}{2r} \qquad (1)$$

B= Magnetic flux density

μ_0 = Magnetic constant (1.2566*10^-6)

N= Number of turns

I= Applied current

r=Radius of coil

b. *Electromagnetic force*

Consider an electromagnet made of a material having constant relative permeability. Current I flow through N number of turns of the coil. The rate of change of energy with gap length i.e. electromagnetic force in Newton is given by

$$F=\frac{B^2 A}{2\mu_0} \qquad (2)$$

F= force in Newton

A= cross sectional area of coil

c. *Displacement*

The displacement of the cantilever beam is given by

$$X=\frac{12FL^3}{8EWT^3} \qquad (3)$$

F= Applied force on the cantilever beam

L= Length of the cantilever beam

W= Width of the cantilever beam

T= Thickness of the cantilever beam

E= Young's modulus of material chosen for cantilever beam

III. MODELING AND SIMULATION IN COMSOL MULTIPHYSICS

The proposed model is developed and simulated using COMSOL Multiphysics software. The dimensions of the electromagnetic actuator without core and with core are listed in table1.

Table1: Dimension of the electromagnetic actuator without core and with core

Cylinder	All dimensions in μm	
	Radius	Height
Coil	10	80

Block	All dimensions in μm		
	Length	Width	Thickness
Air block	120	120	120
Cantilever beam	100	10	2
Core	5	5	10

The material copper is used for coil and the aluminum is used for cantilever beam. Soft iron is used for core.

By taking coil type as circular, coil excitation as current, and selecting the number of turns, model is developed. In solid mechanics physics, fixed constraint is selected and load type is taken as total force along z-direction.

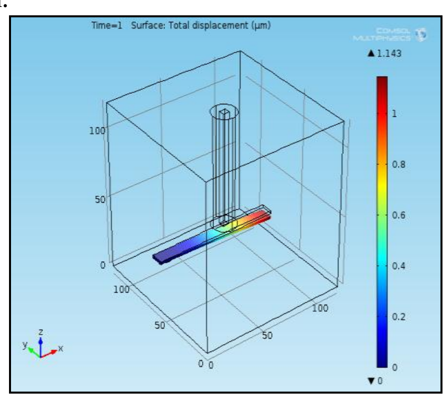

Fig.2 Deflection of Cantilever beam of electromagnetic actuator with core

The simulated result of deflection of electromagnetic actuator with core is shown in Fig.2

IV. RESULT

The simulated results are shown in graphs of Fig. 3 and Fig. 4. In these figures graphical representation of Displacement vs. applied current of electromagnetic actuator without core and with core are presented respectively.

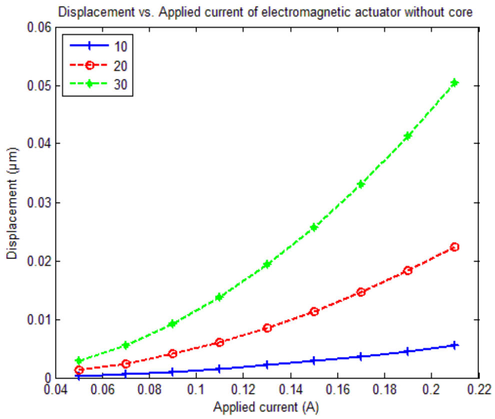

Fig. 3 Displacement vs. applied current of electromagnetic actuator without core

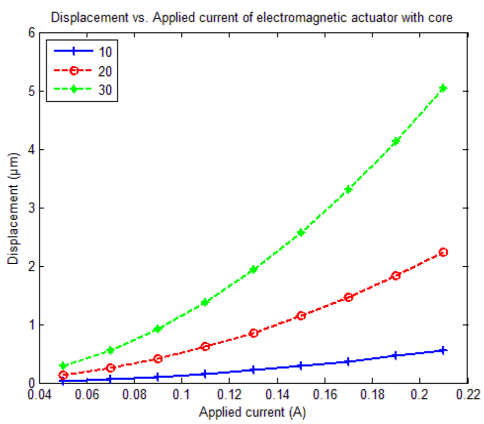

Fig. 4 Displacement vs. applied current of electromagnetic actuator with core

For the electromagnetic actuator without core, considering 10, 20 and 30 number of turns and current of 210mA results are recorded.In this case, displacements obtained are 5.5442*10^-3µm, 0.0224 µm, 0.0505 µm respectively. For micro electromagnetic actuator with core, considering 10, 20 and 30 number of turns and a current of 210mA, once again the results are recorded and they are 0.56 µm, 2.2402 µm, 5.0404 µm respectively.

Fig.5 and Fig.6 represent displacement vs. number of turns of electromagnetic actuator without core and with core respectively.

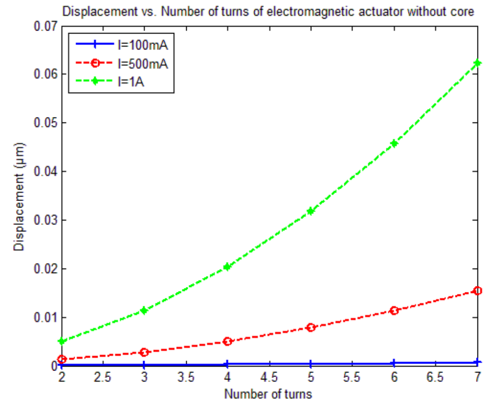

Fig. 5 Displacement vs. number of turns of electromagnetic actuator without core

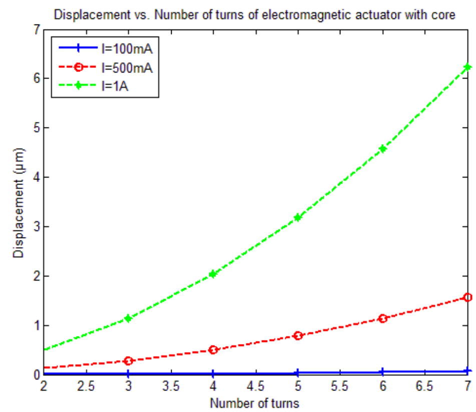

Fig. 6 Displacement vs. number of turns of electromagnetic actuator with core

Micro electromagnetic actuator without core for seven number of turns and current of 100mA, 500mA and 1A is applied, and the simulated results of displacement are 6.1796*10^-4 µm, 0.0155 µm, 0.0624 µm respectively. Similarly for actuator with core, results of displacement are 0.0622 µm, 1.5557 µm, 6.2227 µm.

V. CONCLUSION

In this work 3D model of micro electromagnetic actuator without core and with core is modeled and simulated using COMSOL Multiphysics software. Simulated result of magnetic flux density, electromagnetic force and displacement of electromagnetic actuator without core is compared with micro electromagnetic actuator with core. As the numbers of turns are restricted by the fabrication process minimum numbers of turns are considered. Taking these factors into account, for seven numbers of turns and a current of 1A, a deflection of 6.2227µm is obtained for electromagnetic actuator with core. On considering the minimal current of 210mA, and 30 numbers of turns the deflection is 5.0404µm. By comparing two models of electromagnetic actuator with core and without core, one can conclude that electromagnetic force and displacement of the electromagnetic actuator with core increases by about 100 times more than the electromagnetic actuator without core.

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