Simulation of DC Current Sensor

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Abstract: A proximity DC current sensor using of a piezo sensed and actuated cantilever beam with a permanent magnet mounted at its free end is designed and simulated in COMSOL. The change in resonant frequency of cantilever is a measure of the current through the wire. The sensor is found to be linear with good sensitivity.

Keywords: Piezoelectric; Current Sensor; Magnetic Force;

1. Introduction

Resonant sensors have attracted considerable interest within the research community as they form an excellent device to measure a wide range of parameters such as mass [1], pressure [2] and force [3] etc. The key element of resonant sensor is its oscillating structure, designed to sense the measurand as a function of the natural frequency. The change in the natural frequency of the vibrating element can be accomplished by means of a change in stress, mass or shape of the resonator. The information regarding current flow is required in a wide range of electrical, electronics and instrumentation applications. Various techniques available for current monitoring with their performance and limitations can be seen in [4]. In recent years, an integrated systems approach is being developed to standardize power electronics components and packaging techniques. Therefore the need for micro current sensors suitable for packaging into integrated power electronics modules and integrated passive power processing units increases [5]. The main advantages of integrated sensors are low cost, compatibility, fast response etc. The initial tension and nonlocal stress do play significant roles in the free vibration behavior of a cantilever nanobeam in which the structural stiffness is greatly enhanced [6]. In this paper a micro DC current sensor is proposed, where the DC current is measured in terms of resonant frequency variation of the Piezo laminated cantilever beam. The structure is designed and simulated using COMSOL.

2. Measurement Principle

To measure the DC current, the cantilever structure is placed close to the wire carrying DC current. The force between the permanent magnet and the current carrying wire induces additional stiffness (positive for repulsive force and negative for attractive force) on the structure and hence the resonant frequency of the structure alters. This change in resonant frequency is the measure of the current through the wire.

The measurement system consists of a flexible aluminum beam clamped at one end is shown in Fig 1. Two piezoceramic patches are surface bonded at the fixed end of the beam, patch bonded on the bottom surface acts as a sensor and the one on the top surface acts as an actuator or vice versa. A cylindrical disc type permanent magnet of flux density 1.2 tesla is mounted on the bottom surface of the free end of the cantilever beam and a copper wire of radius 2mm is placed under the magnet in proximity. The radial distance between the permanent magnet and the current carrying wire can be as close as possible. The dimensions of the permanent magnet are 65µm x 20µm and the dimensions and properties of the beam and piezo ceramic patches are given in Table 1 and Table 2 respectively

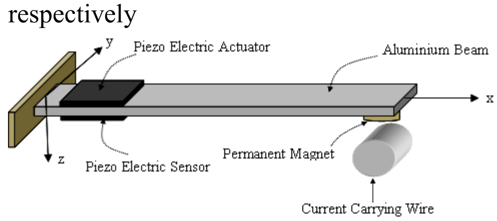
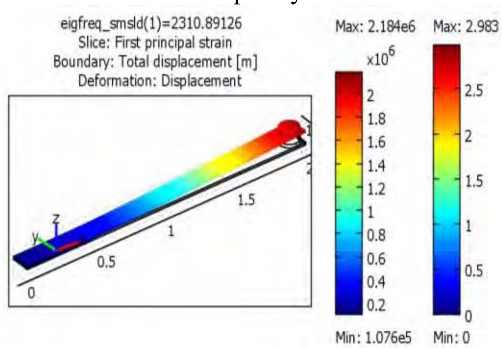


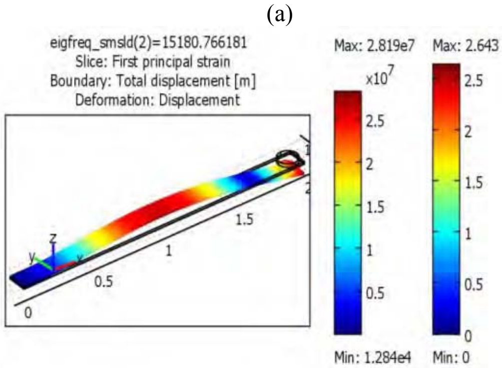
Figure 1. piezo actuated cantilever structure with permanent magnet at its tip

3. Result and Discussion

The structure is built and simulated using COMSOL Multi physics 3.5a version software. The Multi-physics interaction in the measurement system is simulated and analyzed using AC/DC simulator which is a system level simulation module for electromagnetic analysis and MEMS module which is a system level simulation module for piezoelectric and structural mechanics analysis. The MEMS piezo module in COMSOL consists of piezoelectric material database for PZT-2, PZT-4, PZT-4D, PZT-5A, PZT-5H, PZT-5J, PZT-7A, PZT-8. For simulating the measurement system in meso and micro scale the material database of PZT- 5H which is equivalent to NAVY TYPE VI (US DOD MIL STD 1376) in MEMS Piezo module is used. The modal analysis is carried out for the cantilever structure in COMSOL Multi physics and the displacement of the cantilever beam for the first four modes is shown in Fig.2. It is found that the first mode frequency is 2.31089 kHz.



(a)



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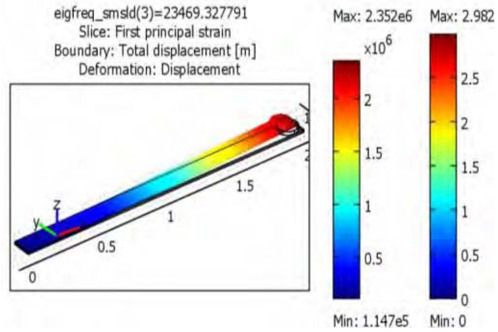

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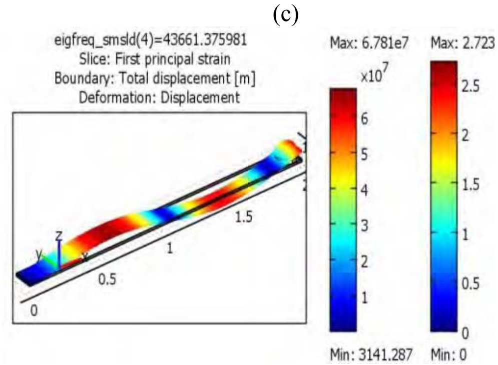
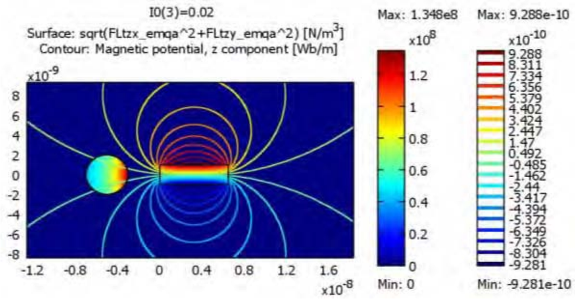


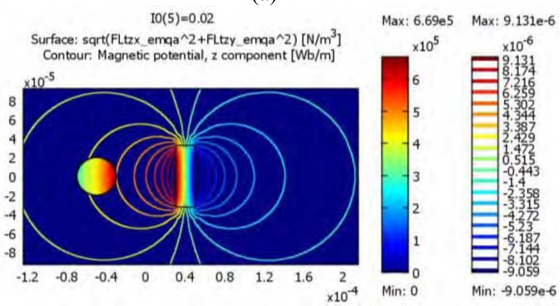
(d)

Figure 2. piezo Simulation model showing modes of vibration (a) first mode (b) second mode (c) third mode (d) fourth mode

To analyze the force acting between the current carrying wire and the magnet placed on the cantilever beam and to find out the optimal orientation of the magnet with respect to the wire, the AC/DC analysis is carried out. The current passing through wire is varied from 0-20mA with the magnet placed in horizontal and vertical directions. From the results it is observed that the force acting on the magnet is found to be high in the vertical orientation. Further the distance between the magnet and the wire is varied to analyze the optimal distance of separation; it is observed that the force acting on the beam is high when placing the wire as close as possible to the magnet. The distance between the wire and magnet is optimized to be 50µm by considering the tip displacement of the cantilever beam at resonance. The simulation results for horizontal and vertical orientations and the force acting on the beam for 50µm distance is shown in Fig. 3.



(a)



(b)

Figure 3. Simulation results for force acting on the beam (a) magnet placed horizontal with respect to wire (b) magnet placed vertical with respect to wire

The resultant force acting on the cantilever beam in the x-direction and the y-direction with the varying current passing through the wire are shown in Fig. 4.

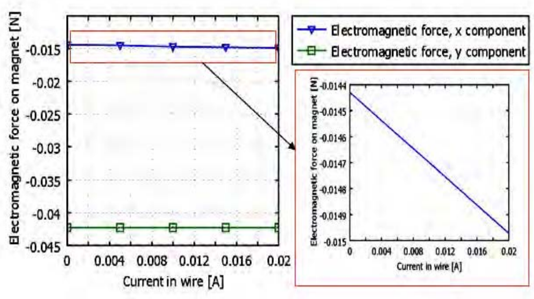


Figure 4. Force acting on the cantilever structure versus current

The applicability of the cantilever based resonant structure for current sensing is tested by applying the force corresponding to the current at the tip of cantilever beam. A shift in resonant frequency of the structure was observed when the structure is simulated in MEMS structural mechanics module of COMSOL multiphysics. It is noted that the shift in resonant frequency of the structure is from 2.31089 kHz to 2.0295 kHz for the current ranging from 0-20mA as shown in Fig 5.

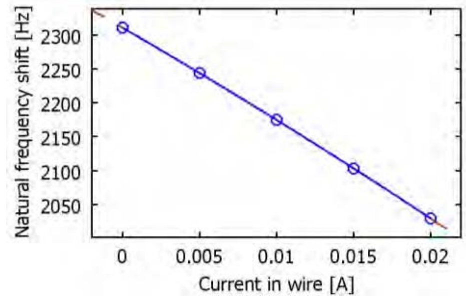


Figure 5. Shift in the natural frequency of the cantilever structure versus current

4. Conclusions

A DC current sensor in micro domain is designed and simulated in COMSOL Multi physics software. The sensor is found to have good linearity and the sensitivity is found to be 12.8Hz/mA. The measurement system suites well for DC current measurement in micro scale devices. The proposed system is simple in design and can easily be fabricated in micro scale to measure DC current of various ranges.

5. References

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6. Appendix

Table 1: Properties and Dimensions of cantilever beam

Length (µm)	l	2000
Width (µm)	b	130
Thickness (µm)	t_b	12.7
Young’s Modulus (GPa)	E_b	71
Density (kg/m^3)	ρ_b	2700

Table 2: Properties and Dimensions of Piezo patch

Length (µm)	l_p	765
Width (µm)	b	130
Thickness (µm)	t_p	5
Young’s Modulus (GPa)	E_p	47.62
Density (kg/m^3)	ρ_p	7500
Piezoelectric strain constant	d_{31}	-247x10$^-$
Piezoelectric stress constant	g_{31}	-9x10^{-3}
Dielectric constant	K_3^T	3100