

Design and Modelling of MEMS based Piezoelectric and Electrostatic Energy Harvester

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ABSTRACT

In this work, Design, simulation and modelling of a Micro Electro Mechanical System (MEMS) based uni-morph piezoelectric energy harvester and electrostatic energy harvester is done. Piezoelectric harvester consists of an active piezoelectric layer, stainless steel substrate and titanium proof mass designed for frequencies 60 Hz - 200 Hz. A two dimensional piezoelectric energy harvester is analysed using Eigen frequency analysis using COMSOL Multiphysics software. The analytical model is validated by comparing the results with 3D finite model. Based on the analysis performed, the length and width of the energy harvester can be chosen. Electrostatic energy harvester is based on inter-digitated comb (IDC) drive structure. The important role of such device is found in applications such as pacemakers, implanted biosensors for diabetics, implanted active RFID devices. Comb drive model is one of the basic model that uses the principle of electrostatics and the force is generated due to vibrations applied. Here Finite element method (FEM) is used to simulate the various physics scenario and it is designed as two dimensional structure in multiphysics domain. The structure is analysed with four fixed and movable fingers then it is extended up to ten fingers and the results are analysed. The characteristics of the energy harvester such as Energy, capacitance, Displacement are analysed.

KEY WORDS: MEMS, piezoelectric, Energy harvester, Electrostatic, Comb drive, Finite element method.

1. INTRODUCTION

Energy harvesting is the process by which energy is derived from the external sources, captured and stored for small, wireless autonomous devices. In this paper design, simulation and modelling of MEMS based Uni-morph Piezoelectric Energy Harvester and Electrostatic Energy Harvester is done using COMSOL software. MEMS consists of miniaturized mechanical and electromechanical elements and the MEMS devices generally range in size from 20 micrometres to a millimetre. The piezoelectric effect converts the mechanical strain into electric current or voltage. A Unimorph piezoelectric energy harvesting system consists of an active piezoelectric layer, stainless steel substrate and titanium proof mass was designed for frequencies in the range 60 Hz to 200 Hz. Electrostatic Energy Harvesting is based on the changing capacitance of vibration dependent capacitors. The vibrations cause the overlap area of a parallel plate capacitor to vary under constant voltage condition. This causes the change of capacitance in parallel plate capacitor and produces electrical energy. Electrostatic Energy Harvester is based on interdigitated comb drive structure. Comb drive model consists of two interdigitated finger structure, where one comb is fixed and the other one is movable. Comb drive model produces large displacement at low voltages. Polysilicon material is applied to the 3D model. FEM (Finite Element Analysis) is used to obtain the results.

Governing equations & theory:

Simple Cantilever beam: Cantilever is a simple beam which is anchored at one end. Cantilever can also be constructed with truss and slabs.

$$f_0 = \frac{v^2}{2\pi} \sqrt{\frac{EI}{12AL^4}}$$

Where E - Young's Modulus, I- Moment of Inertia, A- Area, L- Length of beam, V –natural frequency [$v = 1.875$ for first mode, $v = 4.694$ for second mode].

Unimorph Piezoelectric Energy Harvester: Some of the commonly used piezoelectric materials are Lead Zirconate, Piezoceramics like lead zirconate titanate (PZT) and piezopolymers like polyvinylidene fluoride (PVDF). When beam has only one piezoelectric layer it is called as unimorph. If the piezoelectric layer is sandwiched between the structures then it is called as bimorph. There are various modes in cantilever based energy harvester such as compressive and transverse mode.

In a compressive mode, voltage is applied in three directions parallel to the applied input. In Transverse mode, voltage is applied perpendicular to force input. Mode 31 also known as transverse mode is used as the other mode requires larger mass.

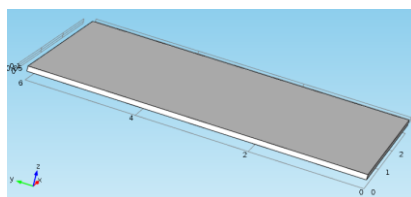


Fig.1. Piezoelectric cantilever beam

The structure is designed using comsol multiphysics 4.2a. A 3D unimorph cantilever is analysed. PZT is used as piezoelectric layer and stainless steel is used as a substrate Fig.1. Output power can be achieved in a cantilever beam when mass is high and less damping factor. So in order to achieve higher output model with proof mass is used Fig.2.

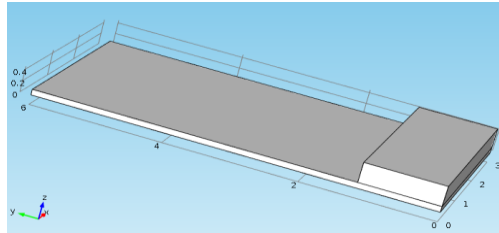


Fig.2. Piezoelectric structure with proof mass

The physics used is Solid Mechanics and the model is meshed with physics controlled and element size is fine Fig.3. Eigen frequency analysis is done for the model.

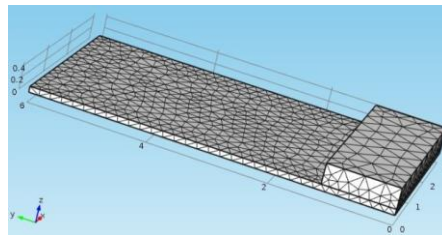


Fig.3. Meshed Model

Design of Interdigitated Comb Drive: IDC MEMS based comb drive structures are widely used in capacitive actuators. Comb drive makes use of Electrostatic forces which acts between two electrically conductive combs. The attractive electrostatic forces are created when a voltage is applied between the fixed and movable fingers.

Analytical calculations: The capacitance effect of the comb drive structure can be analysed using the expression as follows

$$C_0 = \frac{2N\epsilon(y + y_0)T}{s}$$

Where, N - Number of fingers, y_0 - overlapping distance between the fingers, y – Displacement in Y direction, s – gap between the fingers, T – Thickness of the finger.

Electrostatic force can be calculated using the expression given below

$$f = \frac{1}{2} \frac{\partial C_0}{\partial C} V^2$$

Where C_0 is the capacitance with respect to X.

Energy can be calculated using

$$E = \frac{1}{2} C_0 V^2$$

Where C is the capacitance and V is the applied electric potential.

Designing and modelling of Electrostatic based Energy harvester: COMSOL is used to perform simulation in Energy harvester. This technique involves separating the entire structure into a smaller number of discrete geometric entities and then evaluating it to find the entire output. Mesh type ranges from coarse to extremely fine densities. The Physics used here is Electromechanics and the finite element analysis is done using fine mesh. The materials used are Poly Silicon. One set of the finger is fixed at one end along with the truss and the other end is movable. A potential of 5V is applied to the movable comb fingers.

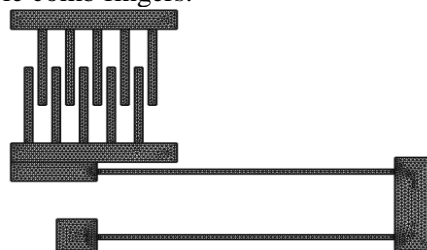


Fig.4. Meshed Electrostatic model

2. RESULT

Piezoelectric: The Eigen frequency analysis has been done for different modes and their simulated results were shown in diagram.

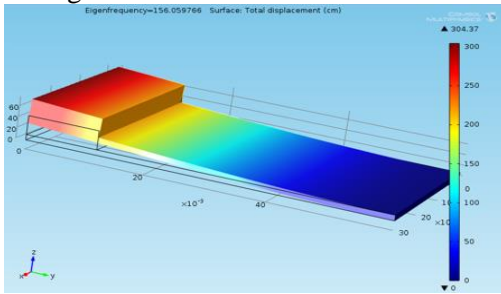


Fig.5. Unimorph simulation model for mode 1

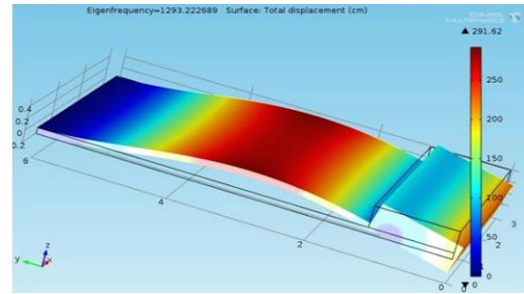


Fig.6. Unimorph simulation model for mode 2

In order to analyze the frequency variations, the length, width and thickness of the beam should be varied. Fig.6, shows that if the length increases then frequency varies which shows that length is inversely proportional to frequency. The width doesn't have any significant effect on frequency, but it may vary slightly as shown in Fig.7.

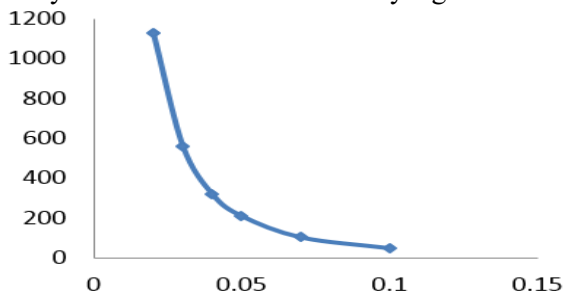


Fig.7. Graph showing the relationship between the frequency and length

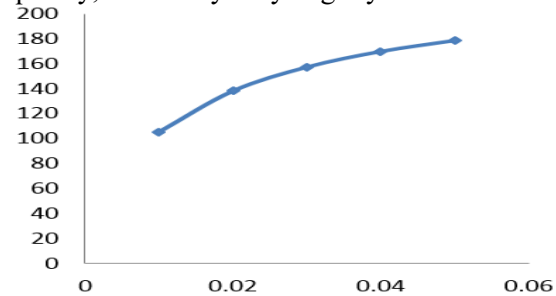


Fig.8. Graph showing the relationship between the frequency and width

Electrostatics: The folded flexure beam is designed with different number of fingers with varying length and the gap between the combs as shown below. Due to this, the displacement is obtained as shown in Fig.12.

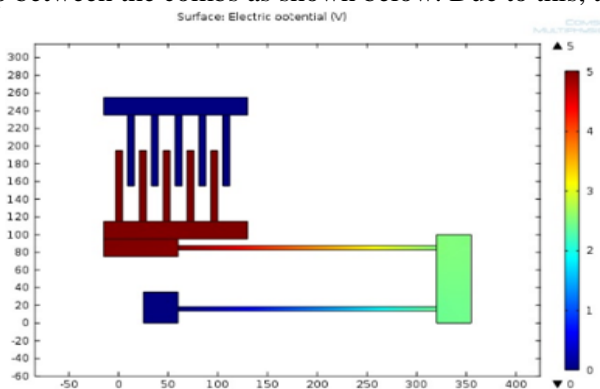


Fig.9. Comb Drive simulation using 5 fingers

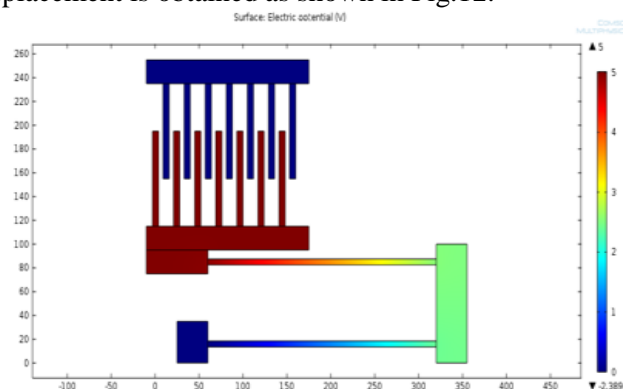


Fig.10. Comb Drive simulation using 7 fingers

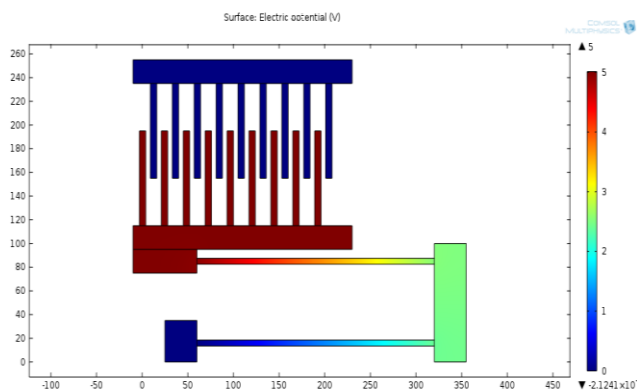


Fig.11. Comb Drive simulation using 9 fingers

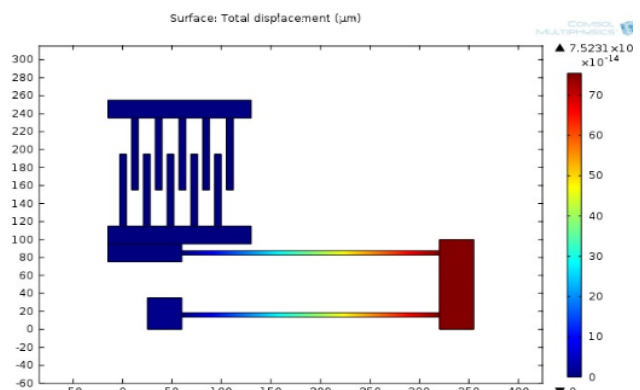


Fig.12. Total Displacement simulated result

In order to obtain an electrostatic force along X direction, 5V is applied to the structure hence energy is produced which is stored in the comb fingers, it acts as a capacitor. The obtained force was about 1.091 which is shown in Fig.13.

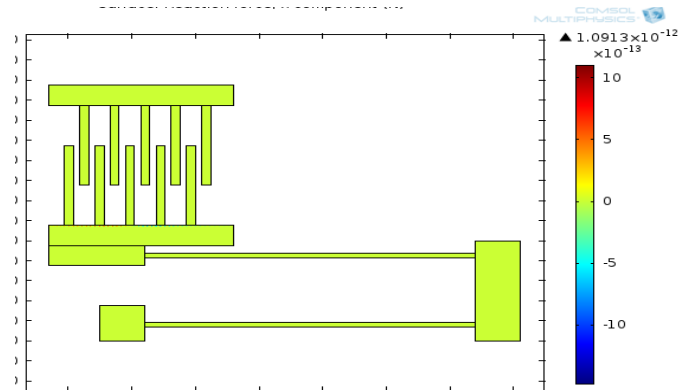


Fig.13. Obtained Force when 5V is applied to it

To increase the electric potential energy, the voltage should be increased accordingly. During large deflections, low driving voltage is to be applied on the structure to get an accurate result. The obtained energy density was about 1.221 which is shown in Fig.14.

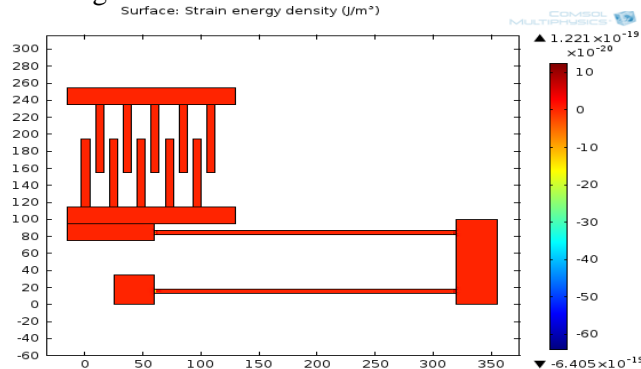


Fig.14. Obtained Energy corresponding to the force

DISCUSSIONS

In Piezo electric energy harvester, eigen frequency analysis result for mode 1 is found to be 156.05Hz and for mode 2 is 1293.22Hz. In electrostatic energy harvester, the analytical calculations has been calculated using formulas given and the values are found and tabulated.

Table.1. Calculated values

No.of fingers	Force (N)	Energy (J)
5	1.5494×10^{-9}	1.2395×10^{-19}
7	2.1693×10^{-9}	3.4721×10^{-19}
9	2.7896×10^{-9}	2.2312×10^{-19}

3. CONCLUSION

The frequency analysis is shown as frequency increased from 100 to 180 Hz by varying the beam width from 0.01 to 0.05m using this unimorph structure, required frequency can be obtained. The simulation design was presented on this paper along with excited resonant frequency. This resonance frequency can be tuneable for 157Hz to 4173 Hz.

In Interdigitated Comb drive, simulation design was designed and simulated using COMSOL Multiphysics 4.2a Software. Here the resonance frequency is tuneable for 17 Hz to 34780 Hz. This comb drive could be used as MEMS micro level applications such as micro tweezers.

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