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Eigen Frequency, Frequency Response, and Transient Response Analysis of MEMS T-Shape Cantilever Beam Piezoelectric Micro-Power Generator About 1 KHz

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***Abstract*—MEMS T-shape cantilever beam Piezoelectric Micro-Power generator (PMPG) harvests mechanical vibration sources available in the surrounding ambient and converts it to electric power necessary for small sensors and small electronics devices via piezoelectric effects, Eliminating the needs for normal battery replacement specially in remote areas, inside human bodies such as artificial pacemaker and artificial cochlea .COMSOL Multiphysics 5.4 is used to simulate PMPG, Eigenfrequency is used to find the resonance frequencies for six Modes of operation and its deflection shape, resonance frequency analysis is used to find the device behavior in frequency rang cover the six mode of operation without external mechanical load, and transient analysis to study the PMPG vibration at first resonance frequency during the first 20 cycle of time. PMPG vibrate up- down in z axis inn first resonance frequency where the neutral axis located inside the proof mass , so no charge cancellation inside the functioning piezoelectric materials occur , the first resonance frequency shows also the maximum total displacement , maximum electric potential across piezoelectric material , and maximum electric energy density over the other resonance frequency mode , the PMPG work probably during transient analysis once driven by sinusoidal signal of frequency equal to first resonance frequency . The PMPG able to work probably in the range of 1300-1600 Hz where the maximum displacement, electric potential, electric energy density occur at 1334 Hz.**

Keywords— Eigen frequency, frequency response, transient response analysis, MEMS, T-shape cantilever beam, Piezoelectric Micro-Power generator

I. INTRODUCTION

Recently , low power requirements of many electronics devices along with its small dimensions due to rapid technology development especially at micro level using Micro electromechanical systems (MEMS) ; which open the door in front of producing self-power devices, solving the problems associating with normal batteries replacement to power electronics devices .

Many techniques are developed to harvest the available mechanical power and convert it to necessary electric power for electronic devices using MEMS technology, such as electrostatic [1, 2,3],electromagnetic[4,5,6] and piezoelectric materials[7,8,9]. Piezoelectric power harvesting technique have advantages over other techniques using MEMS technology, because of both having a better electromechanical coupling and no external source needed [10]. Bridge, diaphragm and cantilever beam structures are the most will know structures in designing and fabricating MEMS piezoelectric micro power generators (PMPG) [11]. Cantilever beam structures get much attentions over other structures due to economic reasons, ease of fabrication, low resonance frequency, and it can produce a superior strain and thus a higher power in comparison to the bridge and diaphragm structures at the same input force [12].

In this paper we design and simulate MEMS PMPG cantilever beam structure able to harvest sound mechanical vibration and convert it to usable electrical power for small electronic devices.

II. DESIGN AND METHODOLOGY

A. PMPG Design

PMPG is MEMS energy scavenging device. In this work, it designed based on Composite T-shape micro cantilever beam, with top proof mass. As shown in figure 1 (a) below .20 μm thickness of silicon single-crystal layers is used as the supported material for the PMPG ,coated with 200 nm of silicon nitride layer as membrane and insulator layer to control residual stresses. A layer of 100 nm platinum (Pt) on top of silicon nitride is used as bottom electrode, it's necessary also to stop lead particles from piezoelectric material to migrate into the silicon single-crystal layers at high temperature during fabrication or polling process [10]. 1.5 μm thickness of PZT-5H piezoelectric material is used as functioning material in PMPG design, which is able to convert the strain induced to electrical charge via piezoelectric effect. Another layer of 50nm of Pt on top of functioning layer as a top electrode to perform .finally, 20 μm of aluminum (Al) used as a proof mass for controlling the resonance frequency and to prevent the location of neutral axis to be located inside the PZT functioning material, figure 1 (b) below shoe the cross section of PMPG device layers. The neutral axis where the cantilever beam doesn't show tension or compression

During vibration. So all electrical charge collected on both side of piezoelectric material shows positive or negative voltage and no charge and hence voltage cancellation occur during vibration.

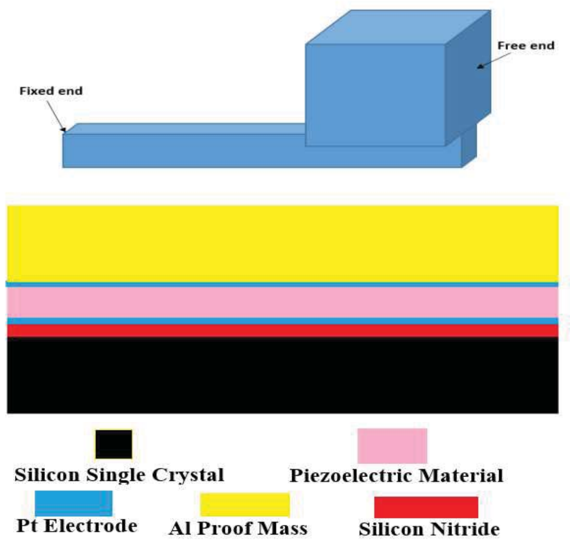


Figure 1. PMPG 3-D T shap , PMPG cross section

B. *PMPG Simulation*

COMSOL Multiphysics 5.4. 3D MEMS module – structural mechanics – Piezo solid is used to simulate T-shape cantilever beam PMPG structure.

Free Mesh Parameter was used to set the mesh. The mesh quality and its predefined mesh size, was chosen to a Coarser, X and Y directions scale factor of 0.1, Z direction scale factor of 1.0., and the resolution of geometry of 20.With maximum element scale factor of 1.0, element growth rate 1.5, mesh curvature factor of 0.6, curvature cut off of 0.03, and resolution of narrow region of 0.5.

COMSOL Multiphysics 4.2 software is used for three basic analysis types which is Eigenfrequency, frequency response, and Transient analysis is used to study the PMPG device.

During free vibration, PMPG operates at more than one resonance frequency. The purpose of the Eigen frequency analysis is to find the lowest six resonance frequencies and their subsequent shape modes. In order to find the most suitable modes of operation for PMPG during vibration. The frequency response analysis is used to find the T-shape cantilever beam displacement in all directions, electric potential, and electric energy density collected at functioning piezoelectric material during vibration at selected PMPG device resonance frequency. While the transient analysis is used to study the device produced voltage, electric charge density and T-shape cantilever beam displacement as functions of time during vibration.

The boundary conditions for the static Eigenfrequency, frequency response, and Transient analysis is set such that the fixed supports at the left beam ends were assumed ideal, while the rest of the structure had no constraints (free).all piezoelectric boundary electric condition are set to zero charge symmetry except the top side which was set as electric potential and the bottom side was set as ground.

III. RESULTS AND DISCUSSION.

The PMPG simulation using COMSOL Multiphysics 5.4 using finite element method to solve engineering problems mesh statistics shows 71542 degree of freedom, 2929 mesh point , 13207 of tetrahedral elements ,4680 triangular boundary elements , 369 number of edge element , 22 vertex elements, 0.0304 minimum element quality , and 0.000676 element of volume ratio.

Eigenfrequency analysis is used to find the first six mode of operation shown below in fig 2. In the first mode, the PMPG resonate at 1334.09 Hz and vibrate up and down in Z direction , in the other modes as shown in fig 2, b-f , the PMPG shows a twisting or other movements rather than up and down . The first mode is preferred over the other mode to prevent charge cancellation inside the functioning piezoelectric materials during vibration.

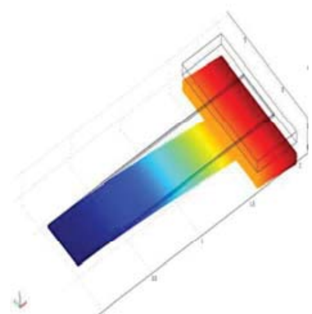


Fig 2. (a). 1st mode at 1334.09Hz

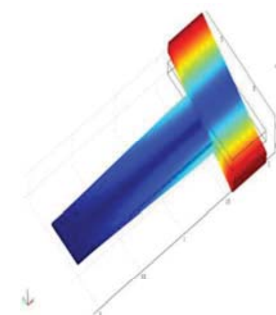


Fig 2. (b). 2nd mode at 7137.70 Hz

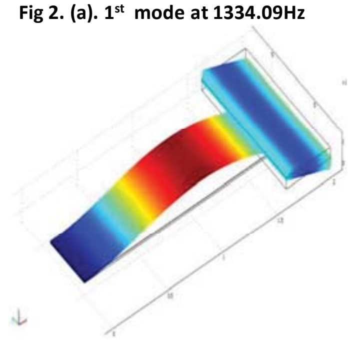


Fig 2. (c). 3ed mode at 17824.95 Hz

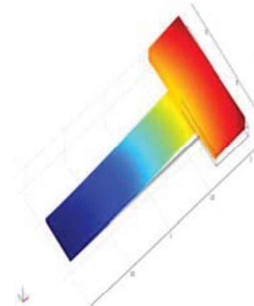


Fig 2. (d). 4th mode at 46450.03 Hz

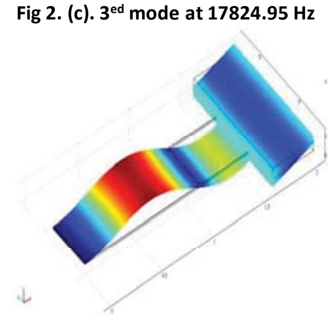


Fig 2. (e). 5th mode at 57908.32 Hz

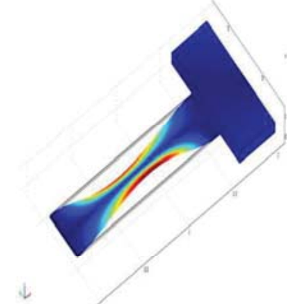


Fig 2. (f). 6th mode at 111430.70 Hz

Fig 2. PMPG First six mode of operation.

In frequency response analyses, The PMPG is simulated in frequency range to cover all first six mode of operation from [0-120] KHz. Without applying any mechanical load to the PMPG device same as Eigenfrequency, the PMPG vibrate at the resonance frequency due to its weigh, the maximum total displacement measured at the center of the proof mass for PMPG occurs at

The first mode of operation at 1334.09 Hz as shown in Fig. 3a, while it's negligible at the other mode of operation, therefore maximum PMPG output power occurs at this mode. The first mode of operation is needed not only because of the maximum displacement but also the other modes do not show a uniform bending of cantilever beam. Therefore some parts of cantilever beam show compression while the other shows tension and causes charge cancellation along cantilever beam, and reduces PMPG output power and its efficiency [7]. Fig. 3, b,c, and d shows the PMPG displacement in z, y, and x axis respectively , it's clear that the total displacement is covered by Z displacement while the other displacement at y and x axis is negligible at first mode of operation . As a displacement result the electric potential and electric energy density is occur primly at first mode of operation as shown in Fig 3 e and f respectively.

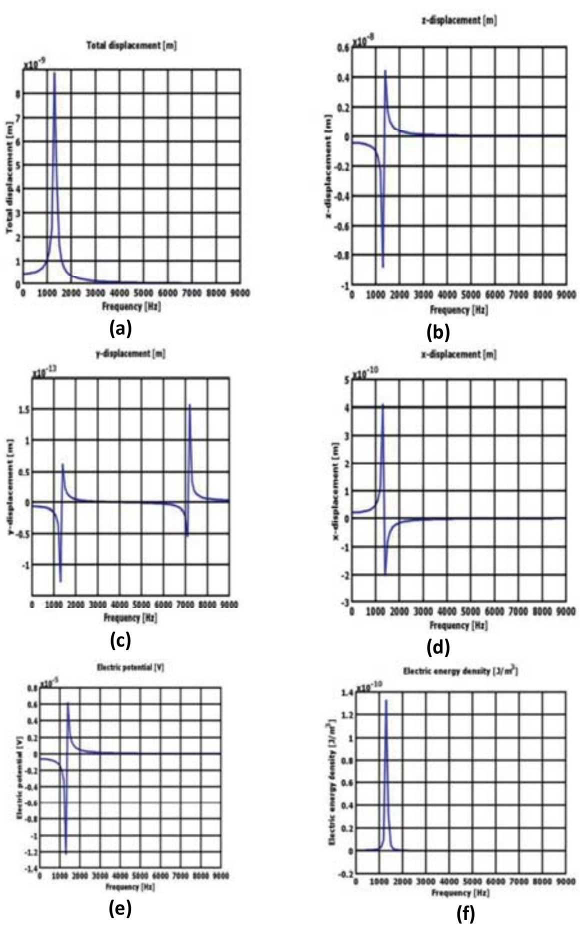
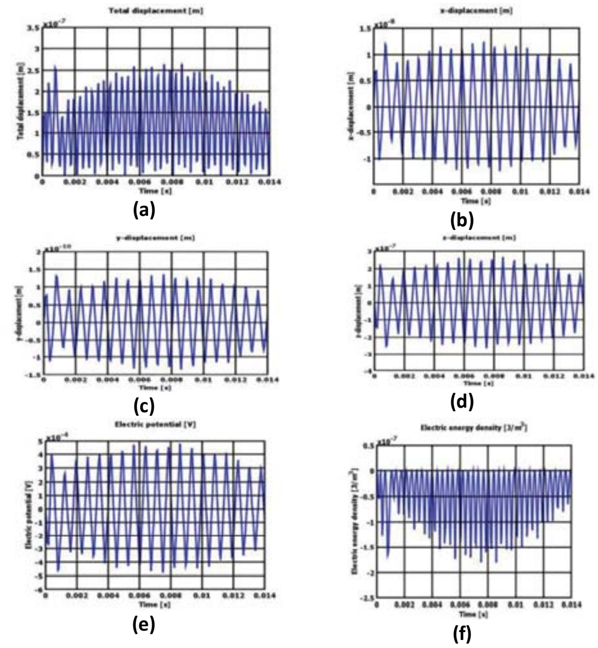


Fig 3. PMPG Frequency reponce analysis in range 0-9 KHz .

In transient analysis , we supplied the PMPG using sinasoidal signal at frequency of 1334.09 Hz , and then we studied the behaviour of PMPG during the first 20 cycles of



time . the device shows stable behaviour during that time which improve the PMPG design and its ability to work probably at this frequency and convert the mechanical energy into electrical energy necessary to small electronic devices .

Fig. 4 . PMPG transient analysis during first 20 cycle of time .

CONCLUSION

We designed, simulated MEMS T-shape cantilever beam PMPG that is able to harvest mechanical vibration from 1300-1360 Hz normally available in human sound and converts it to usable electric power in small electronics devices. The maximum displacement and hence the maximum output power occur at 1334 Hz. COMSOL Multiphysics 5.4 is used for Eigenfrequency, frequency response and Transient analysis. The results are in qualitative acceptance and verified each other.

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