MEMS Piezoelectric Vibration Energy Harvester with Three-DOF Responses

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Abstract

Vibration energy harvester can convert mechanical vibration energy into electrical energy and store it in battery for later use. It can create clean renewable energy from vibration movements such as walking, jumping, running, etc. This can convert energy previously wasted into useful energy for charging portable electronic devices, wireless sensors. If such devices are widely used, it can generate a large amount of green energy and help protect the environment. Most MEMS energy harvesters are designed to harvest energy from one direction only. In this research, a MEMS piezoelectric vibration energy harvester with three-DOF (degree-of-freedom) responses is proposed. The device consists of two silicon masses suspended by two sets of T-shape beams from both sides. The four sets of folded beams in both sides allow the mass to vibrate along X direction. The two sets of straight beams allow the mass to vibrate along both Y and Z directions. Piezoelectric material is pre-deposited along the surfaces of the beams. It can convert the vibration energy of beams into electric voltage, which is passed through a rectifying circuit to charge a battery. The device can harvest vibration energy along all three axes, resulting more effective energy harvesting outcome. It is designed and simulated in COMSOL. The proposed MEMS energy harvester can be attached to shoes, tires or other vibrating surfaces to harvest energy from movement of walking, running, driving for clean energy generation.

Introduction

As pollution and global warming caused by over-exploitation of human activities get more and more serious nowadays, developing clean and sustainable energy source becomes a pressing need. Energy harvesting is a conversion technique to generate the electric power from obtainable ambient energy sources which includes thermal gradients, incident light, human body movements and vibrations produced by different sources. In this research, a piezoelectric vibration energy harvester with three DOF responses is proposed. Due to its small size, it can be embedded inside shoes to harvest energy from the vibrations caused by human movements such as walking, running or exercising. The harvested energy is converted into electrical energy and stored in rechargeable batteries for future usage. People around the world walk, run and do exercise everyday. If all the shoes around the world is embedded with such MEMS energy harvester, it can result in tremendous amount of clean energy. This can help protect the environment and it is truly a "green" technology.

Figure 1. Shoe with vibration energy harvester inserted in its sole

Design of Vibration Energy Harvester

The meshed model of the proposed vibration energy harvester in COMSOL is shown in Figure 1. It consists of two mass blocks connected to four sets of folded beams, two straight beams, and two anchors. Piezoelectric thin films are deposited along the sidewalls of the beams. Where there is vibration along X, Y or Z directions, the central mass blocks experience inertial force and cause the beams to vibrate following the external vibration. The resulted stress along the beams causes the piezoelectric films to generate electrical voltage output. This voltage output is then used to charge rechargeable batteries so that the energy is stored for future usage.

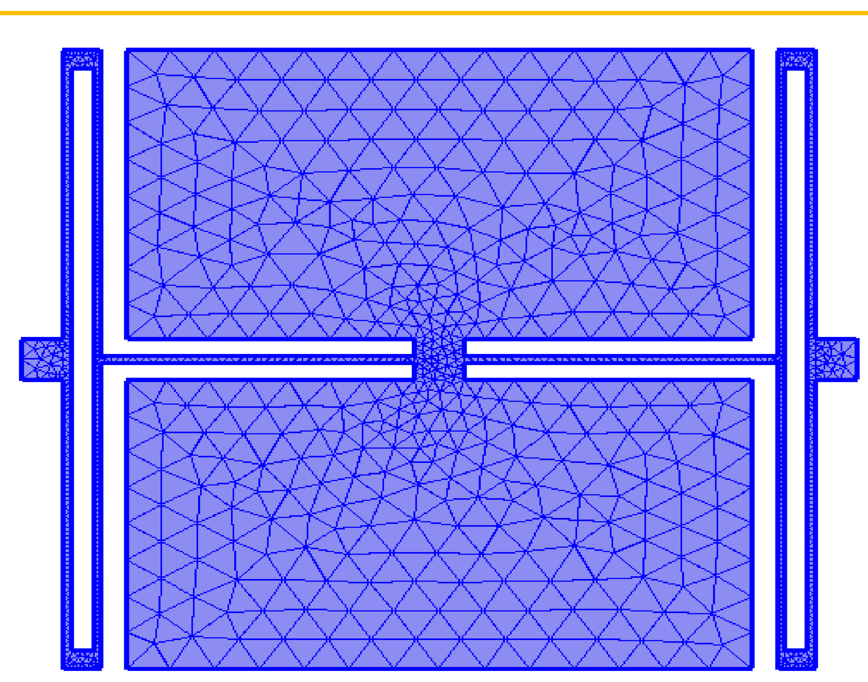

Figure 2. COMSOL meshed model of the MEMS energy harvester

Theoretical Analysis

The vibrational energy harvester uses the vibrations from the T-shape beams to sense the displacement along X, Y and Z axes. The spring constants of the beams along X, Y and Z directions can be calculated as below.

$$K_{x\_tot} = 2EW_{fb}^3 \cdot t_{fb} / L_{fb}^3 \quad (1)$$

$$K_{y\_tot} = 2EW_{sb}^3 \cdot t_{sb} / L_{sb}^3 \quad (2)$$

$$K_{z\_tot} = 2EW_{sb} \cdot t_{sb}^3 / L_{sb}^3 \quad (3)$$

where E: Young's modulus of silicon material,
$W_{fb}/L_{fb}/t_{fb}$: width/length/thickness of one section of folded beam,
$W_{sb}/L_{sb}/t_{sb}$: width/length/thickness of one section of straight beam.
The resonant frequencies of the device along X, Y and Z directions are:

$$f_x = \frac{1}{2\pi}\sqrt{\frac{K_{x\_tot}}{M}} = \frac{1}{2\pi}\sqrt{\frac{2EW_{fb}^3 \cdot t_{fb}}{M \cdot L_{fb}^3}} \quad (4)$$

$$f_y = \frac{1}{2\pi}\sqrt{\frac{K_{y\_tot}}{M}} = \frac{1}{2\pi}\sqrt{\frac{2EW_{sb}^3 \cdot t_{sb}}{M \cdot L_{sb}^3}} \quad (5)$$

$$f_z = \frac{1}{2\pi}\sqrt{\frac{K_{z\_tot}}{M}} = \frac{1}{2\pi}\sqrt{\frac{2EW_{sb} \cdot t_{sb}^3}{M \cdot L_{sb}^3}} \quad (6)$$

Results and Discussion

The MEMS piezoelectric vibration energy harvester device is designed and simulated in COMSOL. Modal simulation is performed on the device to extract its first three vibrational modes and corresponding resonant frequencies. The resonant frequencies along X and Y directions are found to be f_x=1201Hz and f_y=1360.9Hz, as shown in Figures 3 and 4 respectively. The vibration along Z-direction can also be simulated in a similar way.

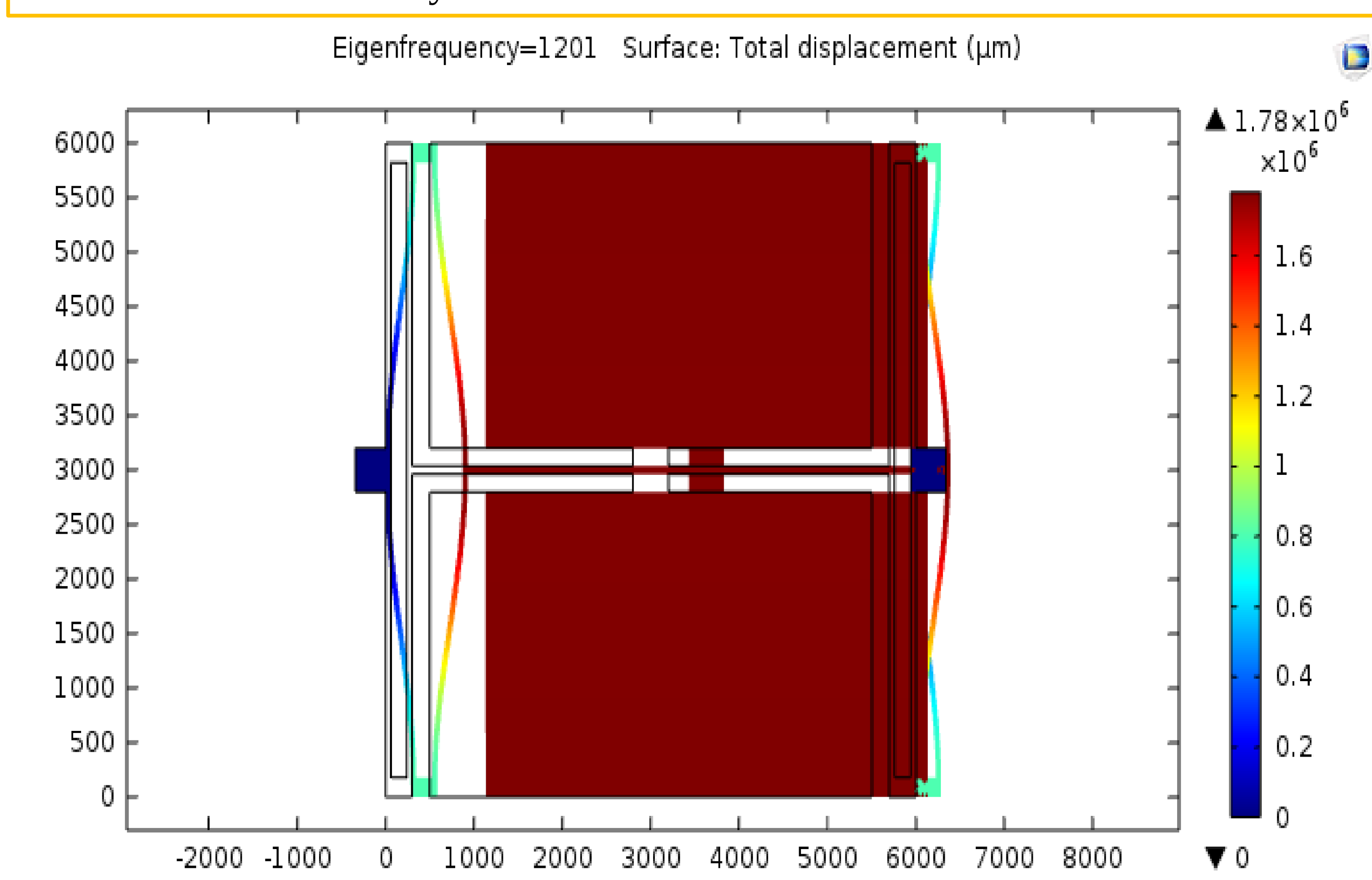

Figure 3 Working mode for vibration along X-direction (f_x=1201Hz)

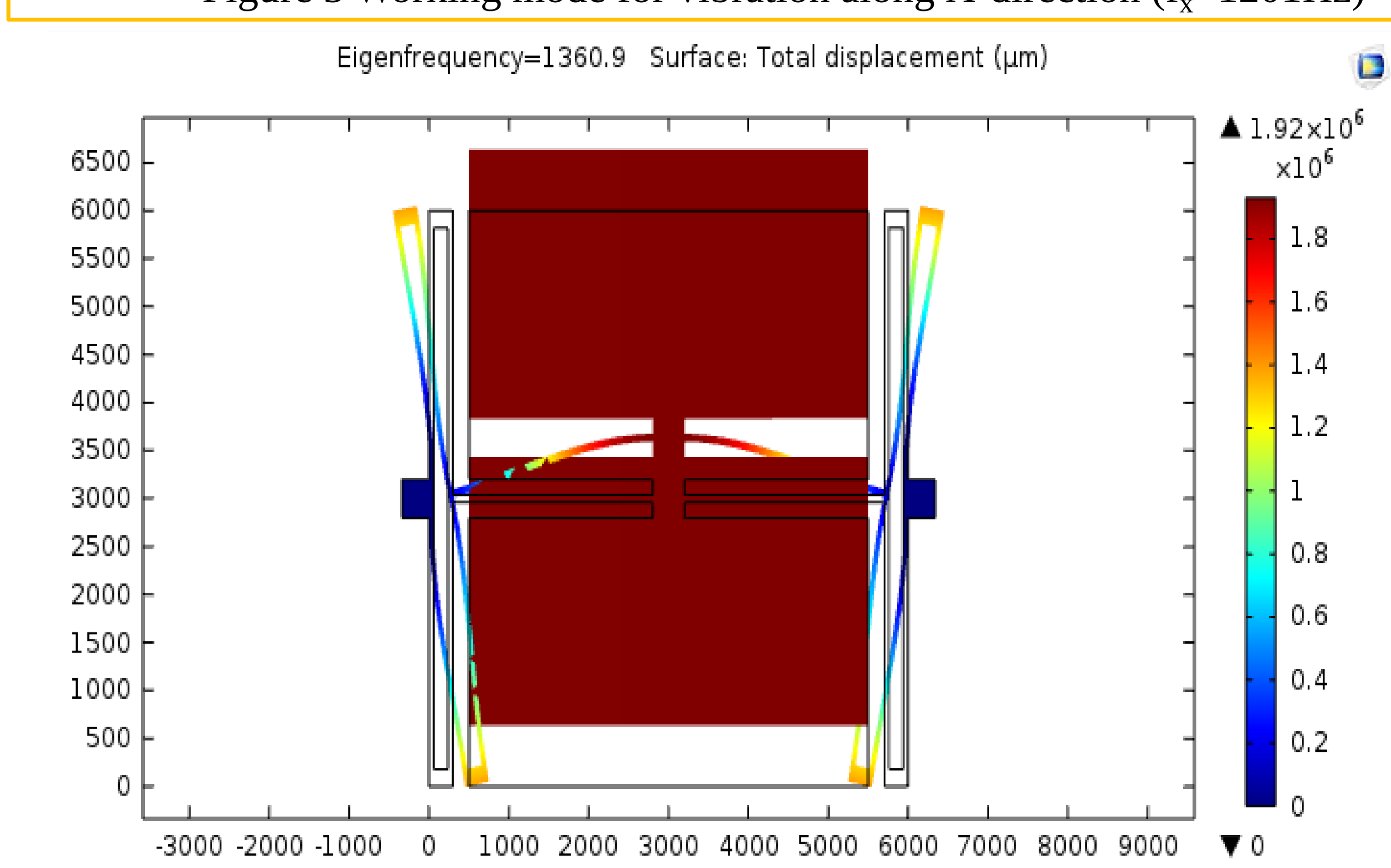

Figure 4 Working mode for vibration along Y-direction (f_y=1360.9Hz)

The vibration energy harvester designed in this research will sense vibrations along all three DOFs. As a result, it is more effective than the energy harvesters which are sensitive only along one direction. Due to MEMS technology, the device size can be very small and it can be easily embedded inside the sole of shoes. When people walk, run or do exercise, the energy of the vibration on the shoes can be harvested and stored in rechargeable battery for future usage. The energy harvester device can be used to charge the battery of backup battery of smart phones, digital camera or other portable electronics. This creates "green" energy and offers a convenient way for people to recharge their cellphone batteries "on-the-run".

Conclusions and Future Work

In this poster, a novel MEMS piezoelectric vibration energy harvester with three-DOF responses is proposed. Compared to energy harvester sensitive to one direction, the proposed device results in more energy harvesting along all directions. COMSOL simulation is used to simulate its vibrational modes and the corresponding resonant frequencies were derived. Due to its small size, it is especially suitable to be embedded inside the sole of shoes, tires, street ground, bridges or any other places with frequent vibrations. It can harvest energy from vibrations where such energy was traditionally wasted. In the future, we will look into the rectifier circuit design of the energy harvester device so that the harvested energy can be used to charge rechargeable batteries or super capacitors.