Modal Analysis Comparison of MDM and SBEH by using FEM

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Abstract - Energy harvesting allows the recovery of the mechanical energy from environmental vibrations and is obtained through the piezoelectric materials according to the direct piezoelectric effect. More in detail, it implies the generation of an electric field across the material corresponding to a mechanical strain. Since past this technology found interesting applications in the framework of wireless sensor systems in order to make the transmission and acquisition units self-powered. The objective of this paper is to study comparative performance of Multi dynamic magnifier (MDM) with single beam energy harvester (SBEH) using modal analysis. Finite element simulation of MDM & SBEH is performed and results are compared. The main aim of this design is to get maximum voltage & power in broad frequency range.

Keywords: Energy harvesting, piezoelectric materials, Magnifier, single beam.

I. INTRODUCTION

The process of acquiring the energy surrounding a system and converting it into usable electrical energy is termed power harvesting. At present, next-generation energy technology is a technology to harvest electrical energy using piezoelectric ceramics based on piezoelectric effect. Piezoelectric effect is the phenomenon where electrical energy is obtained when mechanical energy is applied to piezoelectric ceramic. Technologies are developed because of a shortage of energy in the world. One of the next-generation energy technologies is piezoelectric energy harvesting technology. Piezoelectric energy harvesting technology is very eco-friendly and useful because of the use of discarded physical energy around our living atmosphere. For example, electrical energy is harvested from a vibration of a road when people and cars pass the road. For this method, the piezoelectric energy harvesting technology needs proper piezoelectric generator.

The world energy production sector is in transition and is nowadays called to face great challenges in a context in which the fossil fuel reserves are running out, while the energy demand steadily increases. On the other hand, the rising cost and the related environmental issues make the use of conventional energy resources more and more difficult. The increment of the world energy demand, mainly fulfilled by fossil fuels has brought to an increment in greenhouse gas emissions with serious consequences on our environment. Piezoelectric ceramics discovered in the 1950’s, which experience much stronger piezoelectric effect. The piezoelectric ceramics must undergo a polarizing process for the piezoelectric phenomenon to occur, while crystal materials are naturally piezoelectric. The most commonly used piezoelectric ceramic is lead zirconate titanate (PZT) but also other ceramic materials, such as barium titanate, exhibit the effect. At the turn of the 19th century, Langevin began to make practical applications of "piezoelectric transducers", especially in use of submarine detection under water.

II. LITERATURE REVIEW

Tremendous development in piezoelectric energy generation is observed in last decade. There are so many different techniques invented for energy generation using piezoelectric crystal. A MEMS-based energy harvesting device, micro piezoelectric power generator is designed to convert ambient vibration energy to electrical power via piezoelectric effect by Hua-Bin Fanga & Jing-Quan Liu in 2006. In this work, the generator structure of composite cantilever with nickel metal mass is devised. Device offers the advantage of good performance as far as promising voltage / power output and adjustable low natural frequency to match general vibration sources [1]. Yuantai Hu & Ting Hu analyze a piezoelectric energy harvester as an electro-mechanically coupled system. The energy harvester consists of a piezoelectric bimorph actuator with a concentrated mass attached at one end. They concluded that the power density can be maximized by varying the non-dimensional inductance for a fixed non-dimensional aspect ratio together with a fixed non-dimensional end mass[2]. A nonlinear piezoelectric converter by using permanent magnet is proposed by Marco Ferrari in 2009. Experimental results show that the performances of the converter in terms of output voltage at parity of mechanical excitation are markedly improved [3]. Instead of deposition of PZT bulk film, Huicong Liua made ten PZT thin film patterns (PZT patterns) which are parallel arrayed and electrically isolated on the supporting beam of the cantilever. He studied performance of output voltage and power of PZT patterns in series and in parallel connections based on the experimental and simulation results. It is shown that PZT patterns in series and in parallel connections produce the same level of power in the corresponding matched load resistance, but PZT patterns in parallel connection is preferred because of lower matched load resistance required [4]. Meiling Zhu and Stephen Edkins proposed analytical model results of a cantilever based piezoelectric energy harvesting device (PEHD) with a large tip mass whose centre of gravity is not coincident with its point of attachment to the beam. This work can be used to evaluate the performance of the designed energy harvesting devices for self-power sensors/sensor networks in structural health monitoring applications. [5].

Xianzhi Daia described an energy harvester employing multiple laminated type magneto-electric transducers to convert ambient mechanical vibration into electrical energy. The harvester uses four magnets arranged on the free end of a cantilever beam. Experimental results indicate that the harvester employing multiple transducers can provide higher power and power density [6]. Diyana & Asan considered unimorph piezoelectric energy harvester to harvest wideband mechanical energy. The results of the frequency response are displayed in the form of voltage within frequency range of 0 to 3500 Hz, at which the comb-shaped piezoelectric beam structure shows better performance as there exist more natural frequencies in the specified range of frequency. It is seen that comb structure can be used to harvest broadband vibration energy [7]. L. Zhoua & J. Suna has done the electrical model with the piezoelectric constitutive equations and the single degree of freedom model. These are combined to describe the energy harvesting performance of shear mode piezoelectric cantilever. The proposed model is used to simulate the frequency dependence of the output peak voltage and power. The model can successfully predict the coupled electrical and mechanical responses of the piezoelectric cantilever [8].

III. THEORY

3.1 Single beam energy harvester:

The vast majority of piezoelectric energy harvesting devices uses a cantilever beam structure. A cantilever beam, by definition, is a beam with a support only at one end, and is often referred to as a “fixed-free” beam. When the generator is subjected to vibrations in the vertical direction, the support structure will move up and down in sync with the external acceleration. The vibration of the beam is induced by its own inertia; since the beam is not perfectly rigid, it tends to deflect when the base support is moving up and down. Typically, a proof mass is added to the free end of the beam to increase that deflection amount. This lowers the resonant frequency of the beam and increases the deflection of the beam as it vibrates. The larger deflection leads to more stress, strain, and consequently a higher output voltage and power [9].

Electrodes covering a portion of the cantilever beam are used to conduct the electric charges produced to an electrical circuit, where they can be utilized to charge a capacitor or drive a load. The schematic of the cantilever is shown in Figure 3.1.

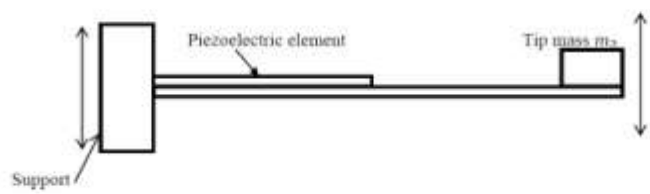

Fig. 3.1 Single beam energy harvester(SBEH)

3.2. Multimode dynamic magnifier (MDM):

The schematic of MDM is shown in the fig. 3.2. A typical harvester is composed of a cantilever beam with tip mass at the end and piezoelectric element film on the beam surface, which operate mainly around the first natural frequency (Fig. 3.1). Innovation here is to take advantage of the fact that the beams have infinite vibration modes as the mechanism of energy harvesting and vibration control[10].

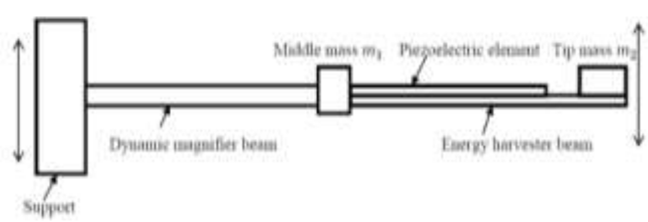

Fig 3.2: Multimode dynamic magnifier

3.3 Finite element analysis:

Finite element method (FEM) analysis is performed in ANSYS. The analysis is performed by considering the beam material as the linear isotropic material. Using ANSYS the structure is tuned. Using the parameters shown in Table 3.1, we got the mode shapes for the first six natural frequencies, while in case SBEH we got 3 modes. Corresponding to each mode we got maximum stress & strain produced in the harvester beam. Then by using relation,

$$V = strain/d \qquad (3.1)$$

Where, V = electric field generated and

d = piezoelectric coefficient in meters per volt

By putting values of strain produced and piezoelectric coefficient in equation (3.1) we calculated the maximum voltage produced at each mode. The piezoelectric material considered here is Lead Zirconate Titanium. For lead zirconate titanium (PZT) value of d is 3.6×10^{-10}m/V

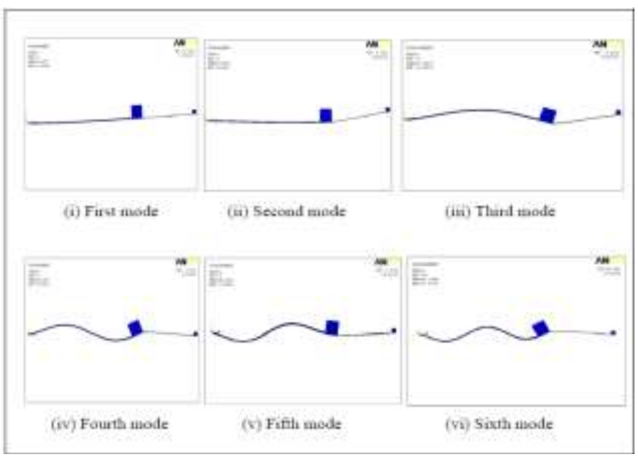

Fig 3.3: Mode shapes of MDM

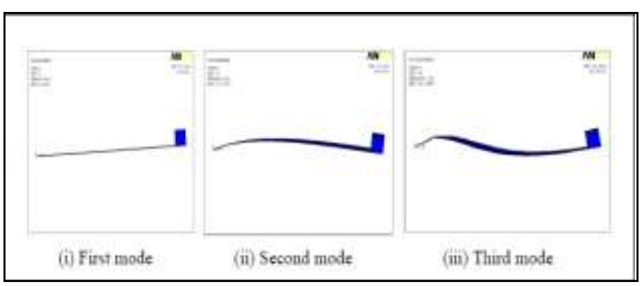

Fig 3.4: Mode shapes for SBEH

Fig. 3.3 shows the mode shapes for first six modes of MDM. The MDM is tuned for first six modes in the frequency range 0 Hz to 100Hz. Fig. 3.4 shows mode shapes for first three modes of SBEH. It is tuned for first 3 modes in the frequency range of 0 Hz to 1000 Hz. We got only one mode of SBEH in frequency range 0 Hz to 100 Hz.

IV. RESULTS AND DISCUSSION

Modal analysis of both SBEH and MDM is performed in ANSYS. Fig. 3.5 shows comparison plot of maximum stress Vs frequency for MDM and SBEH. Fig. 3.6 shows the histogram of maximum voltage generated by PZT Vs frequency for SBEH & MDM respectively. Fig. 3.7 shows the comparison plot of maximum voltage generated by PZT Vs frequency for MDM and SBEH. The highest voltage given by SBEH is 152.5 mV at 886.70 Hz frequency while highest voltage given by MDM is 150.2 mV at 81.544 Hz. For SBEH three modes are observed in the frequency range of 0 to 900 Hz. If we consider frequency range of 0 to 90 Hz we get only one mode in this range. In case of MDM we get six modes in the range of 0 to 90 Hz. This indicates increase in the bandwidth of an energy harvester because of dynamic magnifier.

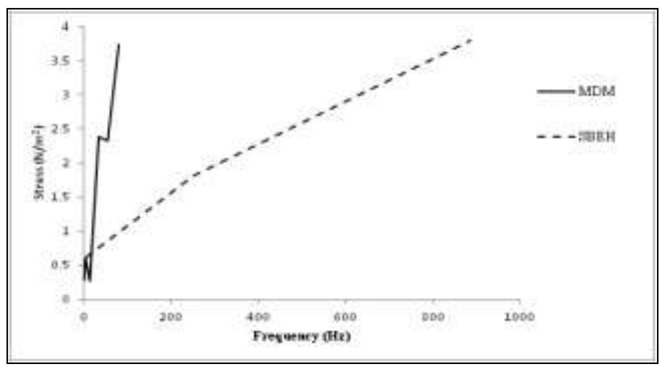

Fig 3.5: Comparison of Maximum stress Vs Frequency for both MDM and SBEH

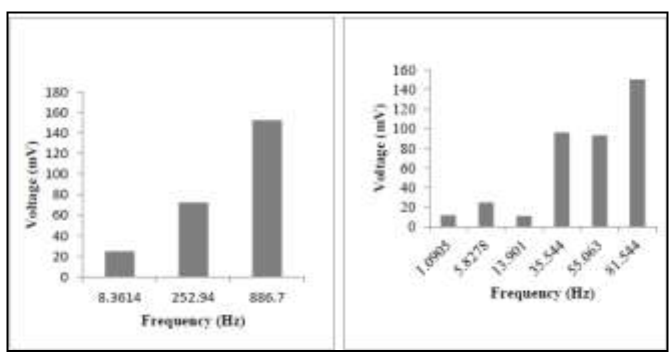

Fig 3.6: Voltage Vs frequency of SBEH and MDM

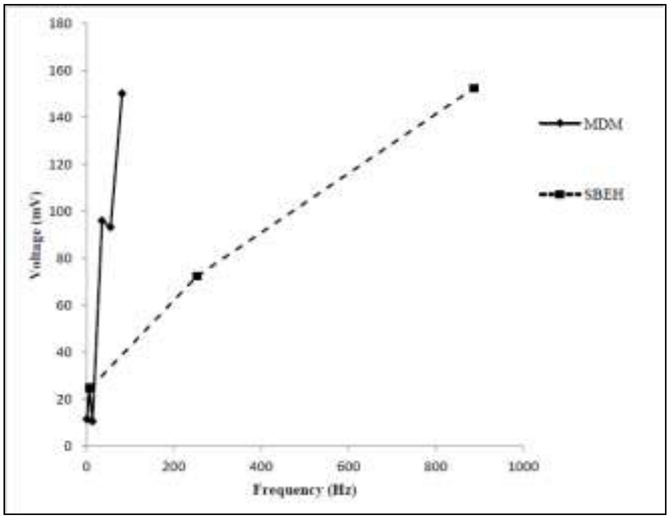

Fig 3.7: Comparison of Voltage Vs Frequency of SBEH and MDM

V. CONCLUSION

In this section a novel design of MDM for efficient energy harvesting is analysed. Finite element simulation is done for modal analysis. By SBEH we get three modes in the frequency range 8 to 886 Hz. While in case of MDM we get six modes in the frequency range 1 to 82 Hz. Below 90 Hz we get 6 modes in MDM & only 1 mode in SBEH. This indicates that MDM is far more efficient than SBEH over a bandwidth of 0 to 90 Hz. It gives peak voltages at six different natural frequencies while SBEH gives it at only one natural frequency. Thus finite element simulation result shows increase in bandwidth of energy harvester in MDM.

VI. REFERENCES

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