# Parametric Analysis of Piezoelectric Energy Harvesting Devices

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***Abstract*—** Piezoelectric energy harvesting has been the aim of many research efforts in the past decade due to the advancement in low-power microelectronics and the promising electromechanical capability of piezoelectric material which converts mechanical strain into electric charges and vice versa.. The aim of this work is to provide a preliminary parametric study for piezoelectric energy harvesters to analyze the effect of the structural geometry on the performance characteristics of the harvester. The beam-piezo-rectifier system is numerically modeled using a finite element model with piezoelectric capability.

***Keywords*—** Energy Harvesting, Piezoelectric, Vibration, Finite Element

## I. INTRODUCTION

PIEZOELECTRIC (PZT) materials have the ability to convert mechanical strain into electric charges and vice versa, which makes them suitable for sensing and actuation applications. The advancement of micro-electro-mechanical systems (MEMS) and microelectronics reduces the power consumption of electronic devices. Hence, piezoelectric energy harvesters will have a valuable role towards the future of self-powered devices. The optimization of piezoelectric harvesters has been tackled in two ways. The first way is to maximize the voltage output from the piezoelectric electrodes in the structural level, which can be done by optimizing the geometry and/or the topology of the device layers. In example works, the piezoelectric layer layout was studied without optimization by suggesting distribution functions [1], while the topology of the piezoelectric layer is optimized to maximize the stored electrical energy in [2]. The topology optimization problem was further tackled to maximize the average power of a harvester over a specified frequency domain due to random vibrations [3]. The second way is to maximize the power at the load by minimizing the losses in the circuit level, which is achieved by optimizing the circuit elements. Many research works are available on the circuit level, which implemented various types of rectifiers as can be seen in [4-6]. In this work, a preliminary optimization study of the piezoelectric harvester is performed through parametric analysis at the first mode of vibration for geometrical variables of the device and results are accordingly withdrawn.

## II. THEORETICAL ANALYSIS

The electromechanical finite element model is derived from the extended variational principle for piezoelectricity, where the kinetic energy *T*, potential energy *U*, and non-conservative work *W* are given by:

$$\int_{t_1}^{t_2} \left( \delta T - \delta U + \delta W \right) dt = 0 \qquad (1)$$

Upon substitution of the discretized energies and work in the above equation, the matrix equations of motion for the harvester in the *s* Laplace domain becomes

$$\begin{bmatrix} \mathbf{M}s^2 + \mathbf{C}s + \mathbf{K} & -\mathbf{K}_{u\theta} \\ \mathbf{K}_{u\theta}s & C_p s + 1/R \end{bmatrix} \begin{Bmatrix} \mathbf{X} \\ \mathbf{V} \end{Bmatrix} = \begin{Bmatrix} \mathbf{F} \\ \mathbf{0} \end{Bmatrix} \qquad (2)$$

With **M**, **C**, **K** and $\mathbf{K_u\theta}$ denote the mass, damping, stiffness, and piezoelectric coupling matrix, respectively. Also, $C_p$ denotes the capacitance of the piezoelectric layer and R is the resistor shown in Fig. 1. Finally, **X**, **V** and **F** are the displacement, voltage, and harmonic base excitation vectors respectively.

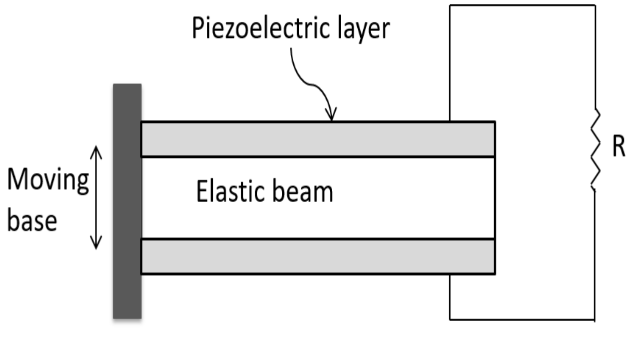

Fig. 1 Piezoelectric energy harvesting bimorph

## III. RESULTS AND DISCUSSION

The parametric analysis is carried out for a unimorph energy harvester that is made of a 100 mm long beam. First, the voltage output from the piezoelectric layer (across the resistor, $R = 1000\ \text{k}\Omega$) is found for varying thickness ratio ($r = t_p/t_b$) of piezoelectric layer ($t_p$) to the beam layer ($t_b$). Fig. 2 shows that increasing the piezoelectric thickness ratio results in an increase in the voltage by from an amount of 2.1 volts at *r* =

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0.1 to 13.2 volts when $r = 1$. However, the increase is not significant after $r = 0.8$ for which the response is 12.1 volts. It can be seen from Fig. 3 that, decreasing the length of the piezoelectric layer from full coverage to 25% coverage, reduces the voltage output and increase the system's first natural frequency and both phenomena are disadvantages. Fig. 3 also shows that the natural frequency reduces to minimum levels after reaching a maximum value; a fact that may be related to the strain energy increase in the piezoelectric layer, which is directly related to the stiffness of the structures, that is proportional to the natural frequency.

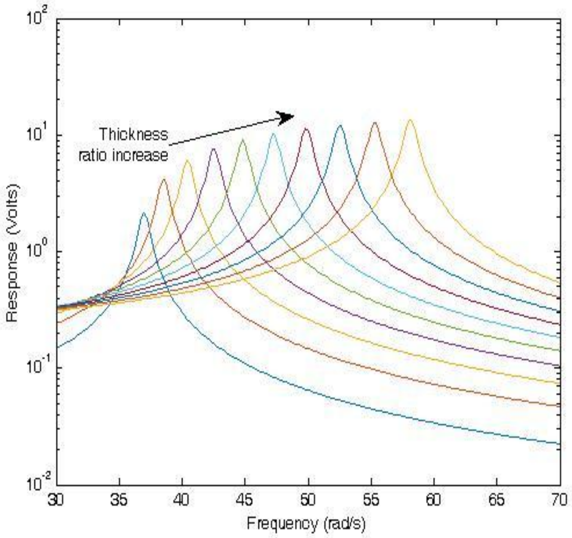

Fig. 2 Frequency response of the voltage across the piezoelectric electrodes with varying thickness ratio

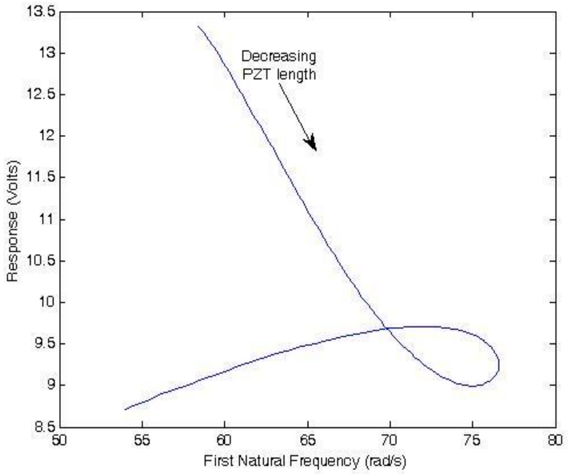

Fig. 3 Frequency response of the voltage across the piezoelectric electrodes with varying length of the piezoelectric layer

## IV. CONCLUSION

The finite element modelling of piezoelectric structures gives the required flexibility to test the response of a piezoelectric energy harvester due to changes in geometrical as well as circuit level parameters. The analysis suggest that the thickness of the piezoelectric layer should be at least 80% of the host beam thickness' to deliver a nearly optimum voltage across the piezoelectric electrodes. The length of the piezoelectric layer also plays in important role in the design procedure since it affects the voltage output across the piezoelectric layer. It is preferred to keep the cantilever beam fully covered to increase the voltage output and decrease the natural frequency of the system.

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