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Modeling and FE Analysis of Vibration Energy Harvesting

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Abstract

Energy (or power) harvesting or (scavenging) is very attractive technique for a wide variety of self-powered micro-systems. By scavenging energy from the environment, miniature sensing/ actuating devices can be self-powered in order to avoid the replacement of finite power sources. The development of micro- systems located in harsh environment further demands for low power consumption and almost no maintenance requirement. Present work aims at modeling and analysis of piezoelectric-based and electromagnetic based vibration-extraction device using Matlab and ANSYS® software. Static and ANSYS®.dynamic analysis of piezoelectric cantilever is carried out

Keywords: harvesting, piezoelectric electromagnetic, wireless, cantilever

1. INTRODUCTION

The rapidly decreasing size and power consumption of sensors and electronics has opened up the relatively new research field of energy harvesting. The goal, of course, is to harvest enough ambient energy to power a standalone sensor and/or actuator system. The concept of energy harvesting, which is a process of capturing ambient waste energy and converting it into useable electricity, was proposed and related research has been highly developed since the past decade to achieve small volume and completely self- powered electronics especially with the recent advent of the extremely low power electrical and mechanical devices such as micro electro mechanical systems (MEMS) make such renewable power sources very attractive.

1.1 Transduction Mechanisms

The advantages and disadvantages points of each mechanical-to-electrical energy conversion method which have been discussed are summarized in the following Table 1.1. From this comparison it is clear that the most desirable conversion method results that piezoelectric one which presents the major number of advantages. So, it is for these reasons that this is currently the best choice to realize the micro vibration-driven generator for energy harvesting to power sensor nodes.

Table 1. Summary of the comparison of the three transduction mechanisms

Type	Advantages	Disadvantages
Piezoelectric	1. No separate voltage source. 2. Voltages of 2 to 10 volts. 3. No mechanical stops. 4. Highest energy density.	Micro fabrication processes are not compatible with standard CMOS processes and piezo thin films have poor coupling.
Electrostatic	1. Easier to integrate with electronics and microsystems. . 2. Voltages of 2 to 10 volts.	1. Separate voltage source needed. 2. Mechanical stops needed.
Electromagnetic	1. No separate voltage source. 2. No mechanical stops.	1. Max voltage of 0.1 volts. 2. Difficult to integrate with electronics and Micro-systems.

1.2 Applications of Vibration Energy Harvesting

Energy (or power) harvesting or (scavenging) is without any doubt a very attractive technique for a wide variety of self-powered microsystems. Examples of such systems are wireless sensors, biomedical implants, military monitoring devices, structure-embedded instrumentation, remote weather station, calculators, watches, Bluetooth headsets. Recently, Nokia announced it is developing a mobile prototype that could harvest energy from ambient radio waves emitted from mobile antennas, TV masts and other sources. Energy harvesting has become of a growing interest in the last few years and research report number has kept increasing for the last decade.

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Objective

The concept of energy harvesting is particularly useful for wireless sensors powered by batteries and remotely operated systems with limited energy source. The goal is to design, and develop such portable vibration energy generation device which can be used in various applications such as mobile charger, power supply to electronics in automobiles etc. One approach to harvest energy is to convert mechanical energy of ambient vibration into electrical energy by electro- magnetic induction or piezoelectric effect. Present work aims at,

- Computer modeling of piezoelectric cantilever using ANSYS®.
- Static analysis of piezoelectric bimorph beam to determine deflection, using ANSYS®.
- Modal analysis of piezoelectric beam to determine the mode shapes, their corresponding modal frequencies and find the % error in frequencies.

2. METHODOLOGY

2.1 Static Analysis of Piezoelectric Bimorph Beam

Piezoelectric bimorph beam is composed of two piezoelectric layers joined together with opposite polarities and is widely used for actuation and sensing. In the actuation mode, on the application of an electric field across the beam thickness, one layer contracts while the other expands. This results in the bending of the entire structure and tip deflection. In the sensing mode, the bimorph is used to measure an external load by monitoring the piezo electrically induced electrode voltages.Fig.1, shows a 2-D analysis of a bimorph mounted as a cantilever. The top surface has ten identical electrode patches and the bottom surface is grounded.

- **Problem specification**

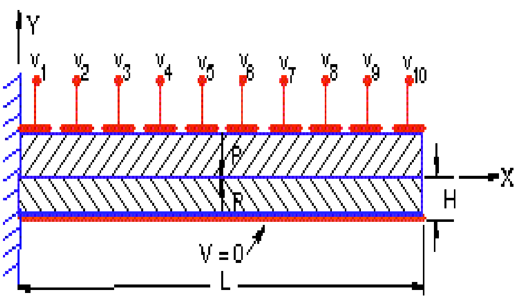

Fig.1 Piezoelectric bimorph beam

The bimorph material is Polyvinylidene Fluoride (PVDF) with the following properties: Young's modulus (E1) = 2.0e9 N/m2

Poisson's ratio (ν12) = 0.29

Shear modulus (G12) = 0.775e9 N/m2

Piezoelectric strain coefficients (d31) = 2.2e-11 C/N, (d32) = 0.3e-11 C/N, and (d33) = - 3.0e-11 C/N

Relative permittivity at constant stress (ε33)

T = 1

The geometric properties are:

Beam length (L) = 100 mm Layer thickness (H) = 0.5 mm

- **Actuator mode**

For applied voltage of 100 volts along the top surface, deflection is determined.

Fig.2 shows the ANSYS® result of piezoelectric bimorph beam for actuator mode.

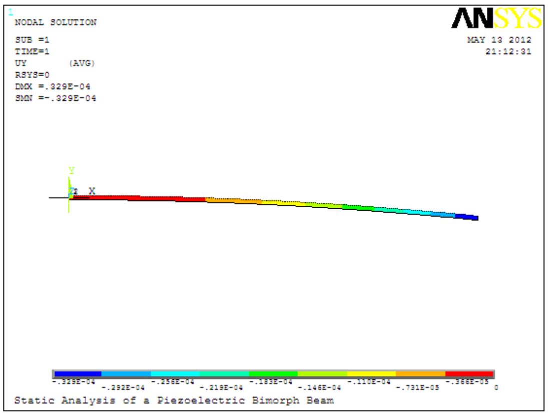

Fig.2. Static analysis of piezoelectric bimorph beam for actuator mode

- **Modal analysis**

Any dynamic response of a system/component can be obtained by superposing its natural modes of vibration when the amplitudes of motion are small. A complete dynamic description of component requires the determination of modal frequencies and modal shapes. Output from modal analysis is natural frequency magnitude and mode shape. For a PVDF piezoelectric beam, first, second and third natural frequency and their mode shapes are obtained below.

Specifications

Young's Modulus E = 2GPa, Density of PVDF =1780kg/m3

Breadth of beam B=20mm, Thickness T=5mm, Length of beam, L=100mm

Area, A=B×T= 100mm2=0.0001m2, Moment of Inertia, I= (B*T3)/12 = 2.0833×10-10m4

First, second and third natural frequencies are obtained by substituting the above values in equation (4.36), (4.37) and (4.38), & are compared with the ANSYS® results.

Fig. 3 to Fig. 5 show the mode shapes of piezoelectric cantilever beam.

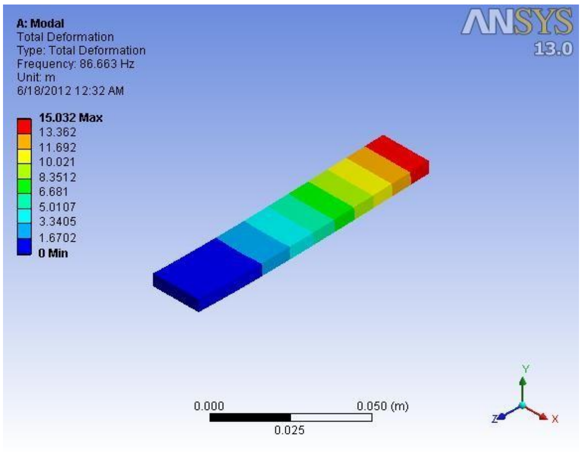

Fig.3 Mode shape -1 of piezoelectric cantilever beam

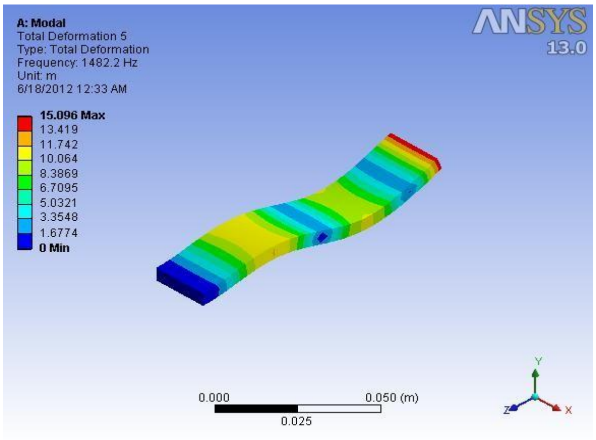

Fig.4 Mode shape -2 of piezoelectric cantilever beam

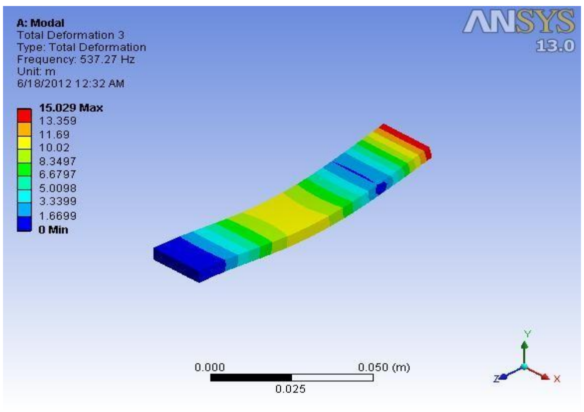

Fig.5 Mode shape -3 of piezoelectric cantilever beam

Table 2- Comparison of frequencies

Mode Shape	Analytical Frequency(Hz)	Frequency(Hz) [ANSYS®]	Error (%)
1	85.591	86.663	1.236
2	536.43	537.27	0.156
3	1502.17	1482.2	1.329

Maximum displacement is 15.096 mm for frequency 1502.17 Hz with error of 1.329%.

3. CONCLUSION

Energy harvesting is useful for wireless sensors powered by batteries and remotely operated systems with limited energy source. Thus to provide electrical energy for such systems the vibrations available in their environment are utilized. Therefore energy is harvested by converting mechanical energy of ambient vibration into electrical energy by electro- magnetic induction or piezoelectric effect.

Modeling and analysis of piezoelectric-based and electromagnetic based vibration extraction devices is done using Matlab and ANSYS® software. Static and dynamic analysis of piezoelectric cantilever is carried out in ANSYS®.

Power generation is mainly dependent on system natural frequency and operating frequency. When these two frequencies are equal resonance occurs and at resonance we can generate large amount of power.

Electromagnetic generator generates power of 1500 milli-Watts, which is sufficient for wireless devices**,** obtained from simulation in Matlab. Single cantilever with piezo patch is modeled it is observed that total power generated is 75 milli-Watts for eight such piezoelectric cantilevers which is sufficient for wireless network applications and small power requirement devices.

Thus the efficiency of power generation using electromagnetic generator is approximately 50 % whereas that of piezoelectric cantilever is 20 %.

Static analysis of Piezoelectric bimorph beam resulted in deflection of -33µm. Dynamic analysis of piezoelectric beam is carried. Modal analysis showed that the comparison of natural frequencies obtained from analytical and are having a close match. The maximum displacement obtained is 15.096 mm for maximum frequency of 1502.17 Hz with error of 1.329

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