

Actuating and Sensing Using Piezoelectric Cantilever

R S Bindu¹, Kushal M Potdar²

¹ Associate Professor and Head of PG Department of Mechanical Engineering
D.Y Patil College of Engineering, Akurdi Pune 411044, India

² Student of Masters in Mechanical Engineering (Design)
D.Y Patil College of Engineering, Akurdi Pune 411044, India

Abstract: *Micro-power generation systems have gained considerable research attention due to the rapid development of micro-electromechanical systems and wireless technologies. To this day batteries serve as the most common power source for remote wireless systems. However, these power systems have grown impractical for large networks and small devices, where replacing depleted batteries becomes difficult. Therefore, alternative solutions characterized by a renewable power supply of reasonable power density have been suggested. Ambient vibrations offer a plausible source of energy for conversion into usable electrical power. Present work aims at modeling and analysis of piezoelectric-based vibration-harvesting devices using Ansys and matlab software. Static analysis of piezoelectric cantilever is carried out in Ansys.*

Keywords: Piezoelectric, Vibration energy, sensing, cantilever, micro-electromechanical

1. Introduction

Energy harvesting from ambient vibrations by using various form of transduction has been recognized as a viable means for powering small electronic devices and remote sensors in order to eliminate their dependence on external power sources such as batteries or power grids. With such self-powered capabilities, these devices and sensors can operate in an uninterrupted fashion over prolonged periods of time. In recent years, interest in energy harvesting has increased rapidly, and harvesting vibration energy using piezoelectric materials has attracted a great deal of attention. Piezoelectric ceramics have been used in many applications to convert mechanical energy into electrical energy. Different types of piezoelectric extraction configurations can be used to harvest ambient vibration energy, Cantilever piezoelectric power generators are being used because of their high strain and high power output even under lower acceleration amplitudes.

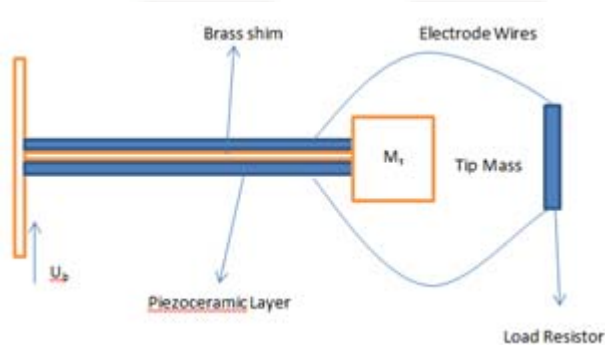


Figure 1: Energy harvesting from piezoelectric bimorph cantilever beam

We aim to perform the static analysis of piezoelectric beam to determine deflections obtained when a voltage is given to the beam

2. The Piezoelectric Effect

The piezoelectric effect, in essence, is the separation of charge within a material as a result of an applied strain. This charge separation effectively creates an electric field within the material and is known as the direct piezoelectric effect. The converse piezoelectric effect is the same process in reverse: the formation of stresses and strains in a material as a result of an applied electric field. The IEEE standard on piezoelectricity lists several different forms for the piezoelectric constitutive equation

$$\epsilon_1 = s_{11} \sigma_1 + d_{13} E_3 \quad (1)$$

$$D_3 = d_{31} \sigma_1 + e_{33} E_3 \quad (2)$$

Where, ϵ = Mechanical Strain

σ = Mechanical Stress

E = Electrical Field

D = Electric Density

s = Elastic Compliance

d = Piezoelectric Strain Coeff.

e = Electric Permittivity

Boundary conditions are denoted by super-scripts. The four boundary conditions that are used are:

T = constant stress (mechanically free)

S = constant strain (mechanically constrained)

D = constant electrical displacement (open circuit)

E = constant field (short circuit).

A cantilever type vibration energy harvesting has very simple structure and can produce large deformation under deformation. The cantilever model can be used in two different modes, 33 mode and 31 mode. The 33 mode (compressive mode) means the voltage is obtained in the 3 direction parallel to the direction of applied force. The 31 mode (Transverse mode) means the voltage is obtained in 1 direction perpendicular to the direction of applied force (3). The most useful mode in harvesting applications is 31 modes, because an immense proof mass would be needed for 33 configurations.

3. Static Analysis of Bimorph Beam

3.1 Actuation Mode

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. We have created an APDL programme using ANSYS for analysis.

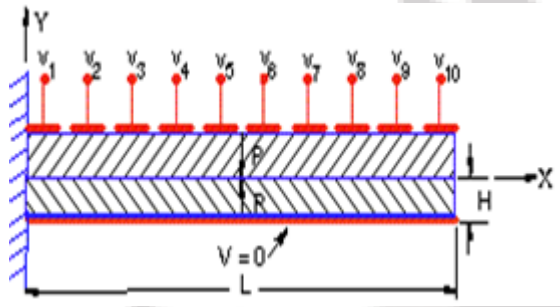


Figure 2: Piezoelectric Bimorph Beam

Figure 2, 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

Configuration details:-

The bimorph material is **Polyvinylidene Fluoride (PVDF)**

with the following properties:

Young's modulus (E_1) = $2.0e9$ N/m²

Poisson's ratio (μ) = 0.29

Shear modulus (G_{12}) = $0.775e9$ N/m²

Piezoelectric strain coefficients (d_{31}) = $2.2e-11$ C/N

(d_{32}) = $0.3e-11$ C/N

(d_{33}) = $-3.0e-11$ C/N

Relative permittivity at constant stress (ϵ_{33})^T = 1

The geometric properties are:

Beam length (L) = 100 mm

Layer thickness (H) = 0.5 mm

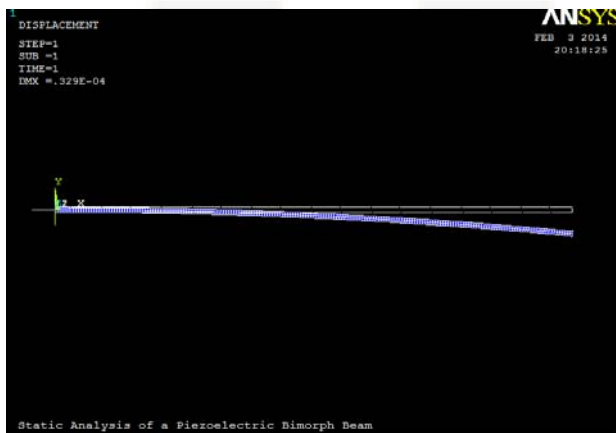


Figure 3: Static analysis of piezoelectric bimorph beam for actuator mode

For an applied voltage of 100 Volts the deflection obtained from Ansys is $32.9\mu\text{m}$. Analytical solution from the equation yields deflection of $-33\mu\text{m}$.

$$U_{y=} = \frac{3VL^2(d_{31})}{8H^2} (3)$$

Where $V = 100\text{V}$, $L = 0.1\text{m}$, $d_{31} = 2.2e-11$ C/N, $H = 0.5e-3\text{m}$

3.2 Sensing mode

In the sensing mode, piezoelectrically induced electrode voltages are determined by giving a tip deflection of 10mm.

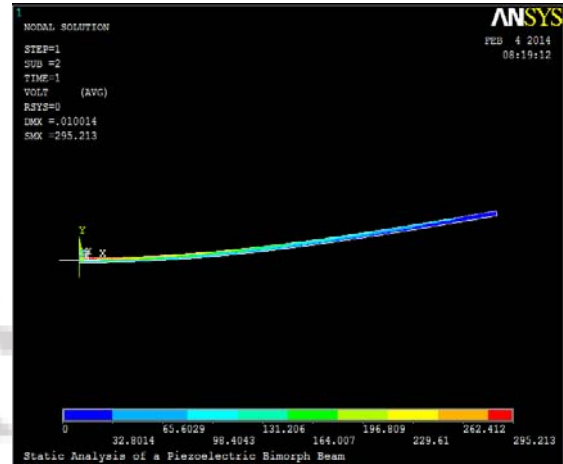


Figure 4: Static analysis for Bimorph beam in sensing mode

4. Conclusion & Scope

From the static analysis of piezoelectric cantilever we conclude that when a voltage of 100V is given to the beam we get deflection of $-33\mu\text{m}$. When a deflection is given to the beam we observe that voltages are generated at the respective electrodes. Thus sensing and actuating can be conveniently done using the piezoelectric cantilever beam. This study provides insights into the use of piezoelectric cantilever beam for the sensing and actuation purpose.

References

- [1] S. Roundy, "On the effectiveness of vibration-based energy harvesting," Journal of Intelligent Material Systems and Structures, vol. 16, 2005.
- [2] Timothy Eggborn, "Analytical Models to Predict Power Harvesting with Piezoelectric Materials", Thesis, 2003.
- [3] Singiresu. S.Rao, Mechanical Vibrations, 4th edition, 2000
- [4] Rupesh Patel, "Modeling, Analysis and optimization of Cantilever piezoelectric energy harvesters" Thesis, 2012

Author Profile



Dr Rupa S Bindu, Associate Professor and Head of PG Department of Mechanical Engineering, D Y Patil College of Engineering, Akurdi, Pune, 44.



Kushal M Potdar, Student of Masters in Mechanical Engineering (Design) at D Y Patil College of Engineering, Akurdi, Pune, 44.