Coupled Field Analysis of Piezoelectric Cantilever Beam by using Finite Element Method

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Abstract— Vibration-based energy harvesting for low-power electricity generation has been heavily researched over the last decade. The motivation in this research field is due to the reduced power requirement of small electronic components, such as the wireless sensor networks used in passive and active monitoring applications. It enables autonomous wireless electronic systems by recovering the waste vibrational energy available in their environment. Vibration-based energy harvester generates the most energy when the generator is excited at its resonance frequency. A Simple model of Aluminium cantilever beam with unimorph piezoelectric patch of PZT-5H is at the end. In this paper the ability of PZT-5H to generate voltage at different frequency range is explained. The work is done in ANSYS and it is validated by experimental analysis. The solid model is design and analyzed using finite element software.

Key words: Piezoelectric Material, Cantilever Beam, Excitation, Vibrational Energy

I. 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. Different types of piezoelectric transducer can be used to harvest vibration energy, including monomorph, bimorph, stack or membrane. Each configuration has its own advantages and limitations, and in general it is not possible for an energy harvester to perform well in all applications. For this reason, energy harvesters are normally designed for specific application and a particular frequency range of operation. Electromagnetic, electrostatic and piezoelectric transductions are the three basic conversion mechanisms commonly used to convert the basic vibrations to electrical energy. Energy density of piezoelectric mechanism is three times higher compared to other means. Researchers have proposed various models to represent the electromechanical behavior of piezoelectric energy harvesters. Especially in the last decade, energy harvesting has often been linked with piezoelectric transducers, since vibrational energy can be easily converted to electrical energy.

Santiago Orrego, et. al [1] has studied the wind energy harvesting performance of inverted piezoelectric flags under controlled and ambient wind conditions. The experiments demonstrated that inverted flags with higher aspect and mass ratios harvested greater quantities of electrical power due to higher bending curvatures and faster flapping frequencies. Aliae Oudich and Frederic Thiebaud [2] have presented an analytical model to analyze the bending of a bimorph beam comprising of piezoelectric material (PM) and shape memory alloy (SMA) thin layers. Using this approach, they investigate thermal energy conversion into electricity by mean of the SMA-PM bimorph. Apler erturk [3] has carried out study on modeling of piezoelectric energy harvester. In this he gave derivation based on Euler Bernoulli, Rayleigh and Timoshenko beam theory with axial deformation. Derivations are used to predicting the electromechanical response of thick cantilevers as well as cantilever with unsymmetrical laminates and varying cross section. Ming li et al., [4] have studied on how to convert rotational energy into electrical energy and investigate influence of the nonlinear dynamic behavior of the harvester on the energy harvesting. They concluded that the maximum voltage is achieved at second order super harmonic resonance rather than main resonance. Aldraihem and Baz [5] have studied electromechanical model of piezoelectric rod with dynamic magnifier and studied the effect of different parameter of the dynamic magnifier on the power output. Bin yang et al., [6] have carried out experiment on the effect of relative position of coils and magnet on piezoelectric cantilever and also studied the effect of poling direction of magnet on output voltage of energy harvester. Maximum voltage gain at poling direction is normal to the coils plain. M. Ferrari, et. al [7] have carried out experiment on a bi-stable energy converter using a ferromagnetic cantilever coupled with external magnet and concluded that there is an improvement in RMS voltage generated by converter when bi-stable behavior is present.

II. FINITE ELEMENT ANALYSIS

In this paper main goal is to determine the peak voltage over a range of frequency encompassing a natural frequency using finite element method and using a representative model of a piezoelectric ceramic material, PZT (lead–zirconate–titanate) with the designation of PZT-5H (lead–zirconate–titanate). The comparison of output voltage produced by PZT-5H with different sizes has been carried out. For this work, specimens with different sizes are considered as described in Table 1.

Specimen. No.	Size of the Substrate Plate (AL) (l*b*t) mm	Size of the Piezoelectric Patch (l*b*t) mm	Piezoelectric Plate Material
1	300 × 50 × 3	100 × 50 × 1	PZT-5H
2	300 × 50 × 3	100 × 50 × 2	PZT-5H
3	300 × 50 × 3	100 × 50 × 3	PZT-5H
4	300 × 50 × 3	100 × 50 × 4	PZT-5H

Table 1: Different Specimens used for the Analysis

A. *Finite Element Method*

The general applicability of the finite element method can be seen by observing the strong similarities that exist between various types of engineering problems. Because modeling of any engineering problem involves the first step to obtain the governing equation of the problem. Mostly these governing equations are in the form of direct or differential for any engineering problem. Obtaining a solution to these governing equations using FEM has common steps. It involves assigning an approximate mathematical function to the elements and correlating this function with governing equations to get algebraic equations. Then boundary conditions are imposed and set of equations is solved to get the solution. .

B. Analysis Procedure

It is a coupled filed analysis as it involves the structural and electrical field analysis together. Hence in the ANSYS software the coupled filed condition has been selected. Any software based FEM analysis consist of preprocessing, solution and post processing. In the preprocessor after defining the elements, material properties and building the geometry the next important step is meshing. In this analysis as the geometry is simple rectangular shaped, the hex-mapped meshing has been carried out after assigning the material attributes to the aluminum and PZT-5H in fig.1.

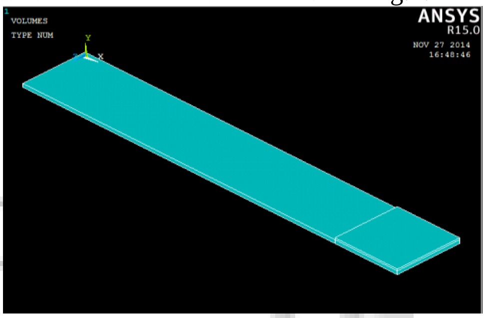

Fig. 1: Model of piezoelectric material perfectly bonded on substrate material

Substrate Material	AL	AL	AL	AL
PZT material	PZT-5H			
PZT Plate thickness	1	2	3	4
Resistor Value (ohm)	3000	3000	3000	3000
Frequency (Hzs)	Specimen 1	Specimen 2	Specimen 3	Specimen 4
20	0.0887	0.0215	0.00215	0.00523
40	0.484	0.398751	0.301656	0.231137
60	2.75151	1.97771	1.42838	1.08181
80	9.31928	6.68062	4.98267	3.99726
100	32.8746	26.5136	25.0068	31.8794
120	100.907	82.1932	29.3981	13.4616
140	50.455	24.2951	12.2511	6.76874
160	28.3941	13.9249	7.12143	3.96424
180	16.56	7.15905	3.20288	1.55343
200	5.80884	1.50909	1.53109	1.46493

Table 2: Comparison of specimen 1 to specimen 4 for the effect on voltage due to the change in thickness of the piezoelectric material by FEA method

III. EXPERIMENTAL ANALYSIS

The experiment is developed in order to test the validity and accuracy of the software model of the cantilever beam. Experimentation is one of the scientific research methods, perhaps the most recognizable in a spectrum of methods that also includes description, comparison, and modeling. While all of these methods share in common a scientific approach. Experimentation gives real insight of the system. In order to find out difference in software and experimental analysis experimentation is necessary. In order to find out voltage rate generated by piezoelectric cantilever beam subjected following instrumentation is required. There are normally four main types of measurement equipment include the excitation equipment, microcontroller system interfaced with MATLAB software, sensing equipment followed by data acquisition and processing equipment. The displacement of 2 mm have been applied for the harmonic analysis to the cantilever beam with the range of 0-200 Hz.

Substrate Material	Al	Al	Al	Al
PZT Material	PZT-5H			
PZT Plate thickness	1	2	3	4
Resistor Value	3000	3000	3000	3000
Frequency Hertz	Specimen 5	Specimen 6	Specimen 7	Specimen 8
20	0.081553	0.019787	0.001977	0.004809
40	0.448384	0.369642	0.279635	0.214264
60	2.498371	1.795761	1.296969	0.982283
80	8.405991	6.025919	4.494368	3.605529
100	30.507629	24.604621	23.20631	29.58408
120	98.282417	76.521869	27.369631	12.53275
140	47.12497	22.691623	11.442527	6.322003
160	26.946001	13.21473	6.758237	3.762064
180	15.50016	6.700871	2.997896	1.45401
200	5.40803	1.404963	1.425445	1.36385

Table 3: Comparison of specimen 1 to specimen 4 for the effect on voltage due to the change in thickness of the piezoelectric material by experimental method

IV. RESULT AND DISCUSSION

This chapter is dedicated to the discussion of the results carried out by FEA and experimental testing of the piezoelectric material. It includes analysis of voltage generation rate by piezoelectric material like PZT 5H.

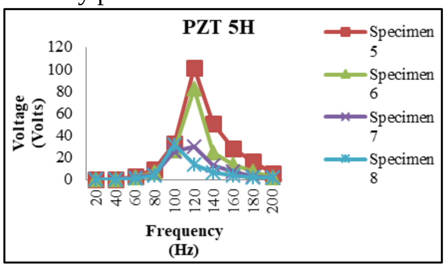

Fig. 2: Comparison of voltage generation rate of PZT 5H of different thickness by FEA method

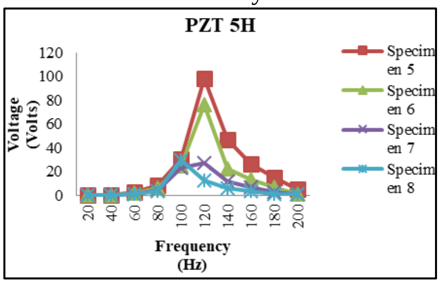

Fig. 3: Comparison of voltage generation rate of PZT 5H of different thickness by experimental method

Figure 2 shows voltage vs frequency graph of piezoelectric plate PZT 5H. Piezoelectric plate conducted in various thicknesses. PZT plate of thickness 1 mm generates maximum amount of voltage. It produces 98.282417 volts at frequency 120 Hz. The cantilever beam vibrates at frequency range from 0 Hz to 200 Hz. The piezoelectric plate starts generation of voltage from and above 20 Hz. The voltage generation rate increases instantly between the frequency 80 Hz to 120 Hz and lowers instantly at frequency range 120 Hz to 140 Hz. So it is preferable to excite a piezoelectric plate PZT 5H of dimension 100 mm lengths, 1 mm thickness and 50 mm width at a natural frequency of about 120 Hz.

V. CONCLUSION

In this paper some preliminary aspects of piezoelectricity have been discussed with the particular reference to the energy harvesting. The energy harvesting from the piezoelectric material can be achieved easily using the vibrational response of same structure the voltage generated through such piezoelectric system is quite small but can be effectively used for small sensors and remote application. It is found that the maximum voltage gain 120 Hz. There is good agreement between FEA result and experimental result.

Therefore the development of energy harvesting system using piezoelectric material is having the vast scope for the researcher. Researcher also has the opportunity to optimize solid model and achieve maximum voltage generation rate.

REFERENCES

[1] Santiago Orrego, KouroshShoele, Andre Ruas, Kyle Doran, Brett Caggiano, Rajat Mittal, Sung Hoon Kang, “Harvesting ambient wind energy with an inverted piezoelectric flag”. Applied Energy 194 (2017) 212-222.

[2] Aliae Oudich, Frederic Thiebaud, “A two-way shape memory alloy-piezoelectric bimorph for thermal energy harvesting”. Mechanics of Materials 102 (2016) 1–6.

[3] Apler Erturk, “Assumed modes modeling of piezoelectric energy harvesters: Euler –Bernoulli, Rayleigh, and Timoshenko models with axial deformations”. Computers and Structures 106–107 (2012) 214–227.

[4] Ming li, Yumei Wen, Ping li, Jin Yang, Xianzhi Dai, “A rotation energy harvester employing cantilever beam and magnetostrictive / piezoelectric laminate transducer”. Sensors and Actuators A 166 (2011) 102–110.

[5] Aldraihem O., Baz A., “Energy harvester with dynamic magnifier”. Journal of Intelligent Material Systems and Structures 2011 22: 521.

[6] Bin Yang, Chengkuo lee, Wei loon Kee, SiakPianglim, “Hybrid energy harvester based on piezoelectric and electromagnetic mechanisms”. J. Micro/Nanolith. MEMS MOEMS 9_2, 023002 Apr–Jun 2010.

[7] M. Ferrari, V. Ferrari, M. Guizzetti, D. Marioli, “A single magnet nonlinear piezoelectric converter for enhanced energy harvesting from random vibrations”. Procedia Engineering 5 (2010) 1156–1159.