Journal of Material Science and Mechanical Engineering (JMSME)
p-ISSN: 2393-9095; e-ISSN: 2393-9109; Volume 2, Issue 13; October-December, 2015 pp. 87-93

http://www.krishisanskriti.org/Publication.html

Harnessing Vibrations from a Light Motor Vehicle using a Thin Aluminium Cantilever Shell

Shreyas Srivatsa[1], B.K. Raghu Prasad[2], Hanumantharaju.H.G[3] and Gaurav M Bhat[4]

[1]*Undergraduate, Dept. of Mechanical Engineering, University Visvesvaraya College of Engineering, Bangalore-01, India*
[2]*Dept. of Civil Engineering, Indian Institute of Science, Bangalore-12, India*
[3]*Dept. Of Mechanical Engineering, University Visvesvaraya College of Engineering, Bangalore-01, India*
[4]*Undergraduate, Dept. Of Mechanical Engineering, University Visvesvaraya College of Engineering, Bangalore-01, India*
E-mail: [1]shreyas0707@gmail.com

Abstract—*Vibrations have a great potential to form energy sources. They are seldom used for this purpose. A device which converts the energy generated from mechanical vibrations of an engine into electrical energy has been fabricated and analyzed. The vibrations of the engine of a light motor vehicle are captured and amplified by a thin-cantilever shell made up of Aluminium. The shell was designed using CATIA software and fabricated. The vibrations at the tip of the cantilever shell are monitored and absorbed by a piezoelectric film which acts as a dynamic-strain-gauge. Due to the direct piezoelectric effect, voltage is developed. The model generated a steady voltage in the range of about 0.3V-0.7 V when the vehicle travels at speeds ranging from 40-70 km/hr. This voltage can be further amplified and stored using capacitors or re-chargeable batteries.*

Keywords*: Engine vibrations, Energy harnessing, Thin-cantilever shell, piezoelectric material.*

1. INTRODUCTION

In the past few centuries, industrialization has led to increased manufacturing of a wide range of machines - which has resulted in fast consumption of Non-renewable and conventional energy sources. It was reported by the United Nations that the consumption of energy will escalate with the expected 2.4 billion increase in population till the year 2050[1]. The International Energy Outlook 2013 (IEO2013) projects that the world energy consumption will grow by 56 percent between 2010 and 2040. Total world energy use will rise from 524 quadrillion British thermal units (Btu) in 2010 to 630 quadrillion Btu in 2020 and to 820 quadrillion Btu in 2040[2].The energy requirement in India for the future will also be high as the number of industries and consumers are increasing every year.

Vibrations and sound generated by vibrations have a great potential to form energy sources. Vibrations of a machine are usually damped to reduce the effects on the machine. Likewise with the decrease in energy consumption of portable and other electronic devices, the concept of harnessing renewable energy in human surroundings aroused a new interest [3]. Convergence of these two concepts has led to usage of these machine vibrations as a source of energy. There have been many works which have utilized these vibrations to generate electrical energy. A piezoelectric generator consisting of a cantilever beam with piezoelectric film attached to it was previously used by E. Minazara, D. Vasic and F. Costa to utilize the mechanical energy available on a bicycle. They converted the mechanical vibrations to electrical energy using the piezoelectric generator fixed to the handle bar of a bicycle. In the first experiment they observed that a few mW of power which was produced by the generator was able to light a LED lamp. They repeated the experiment under certain ideal conditions. [3].

The block diagram of their work has been given below.

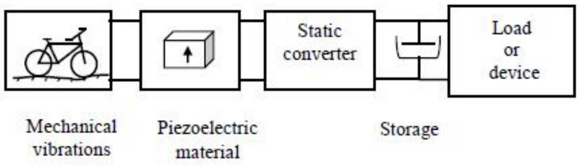


Fig. 1: Block diagram of a piezoelectric generator

Researchers Hausler E. and Stein L. implanted a piezoelectric material of polyvinylidene fluoride (PVDF) patch onto the rib cage of a mongrel dog to harness energy during inspiration. They discussed implanting piezoceramic patches into a living body to harvest power from breathing, more specifically the elongation of the inspiration phase [4].

Kasyap et al caused a cantilever beam to vibrate with a Lead Zirconate Titanate (PZT). The patch was attached in order to produce an electrical charge by direct piezo effect. They harnessed this vibrational energy and stored it using a fly back converter. Using the fly back converter and running the piezoelectric material at resonance, an efficiency of 20% was achieved [5].

Gonzalez et al. discussed portable applications and the power requirements for each device. Low intensity power requirements for communication devices such as Bluetooth and GSM range between 12–18mW.Crawley and de Luis developed many analytical models of mechanical coupling between piezoelectric actuators and substrates. Static models were established to couple structures to several different actuator configurations, including surface-bonded and embedded configurations. These static models were then coupled into a dynamic model of a cantilever beam. They used the Rayleigh-Ritz equation of motion to model the beam. A scaling analysis was also performed to determine how changes in the structure affected the actuator efficiency [7].

Dimitriadis et al. have developed a theory for the excitation of two-dimensional thin elastic structures by piezoelectric patch actuators. This theory was applied to a simply supported rectangular thin plate by piezoelectric patches bonded symmetrically on both sides of the plate. By driving the actuators at the plate’s resonant frequencies, it was possible to excite the individual plate modes. The modal response was directly related to the excitation frequency, patch shape, and patch location [8].

Wang et al.also developed sets of equations for determining the deformation compatibility between piezoelectric patches and beams or plates. The interaction forces between the piezoelectric patches and substrates were caused by structural deformation and an electric field imposed upon the piezoelectric patch[9].

Timothy Eggborn in his thesis constructed a beam and plate model, and extracted there power values. The analytical power values were compared to experimental data in order to determine the most suitable predictive method from vibrational systems. In addition a parametric study was performed on piezoceramic to further optimize the power harnessing process [10].

With the development in the field of smart materials, especially piezoelectric, lots of advancements have been achieved which has helped in the endeavor of harnessing energy. Currently, piezoelectric polymer sensors (piezoelectric films) are among the fastest growing technology and like any other new technology; there have been an extraordinary number of applications [11]. Many such experiments were successful in harnessing several microwatts to mili-Watts of usable power. Storing the energy once it has been harnessed is a project in and of itself.

2. METHODOLOGY

Energy harnessing from any machine was the focus for this work. But based on availability, a Light Motor Vehicle was chosen. The selection of the Light Motor Vehicle (TVS Victor GL) was mainly due to the accessibility. The dimensions of engine and its fins were taken and it was considered as a base structure upon which the thin-cantilever shell would be mounted.

- Commercial Aluminium sheets with varying thickness were used. These sheets were fabricated into the form as specified by the design.

The 2-dimensional design of the model is given in the figure below. (For design and modelling purpose CATIA V5 R19 was used).

- After the fabrication, models made with various thicknesses were mounted onto the engine and hinged.

Here the figure represents the model recreated in CATIA and also 3-dimensional drafted drawing (first angle projection) can be seen:

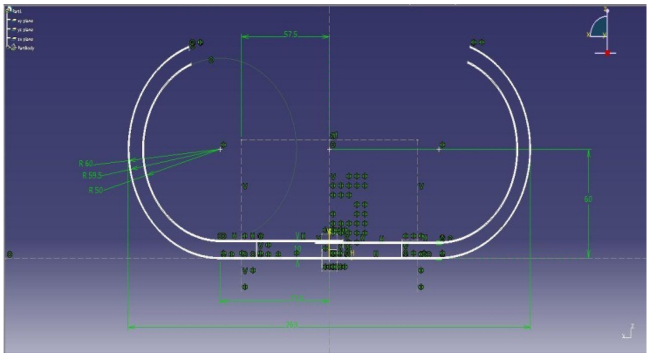


Fig. 2.a: 2D model designed in CATIA V5 R19

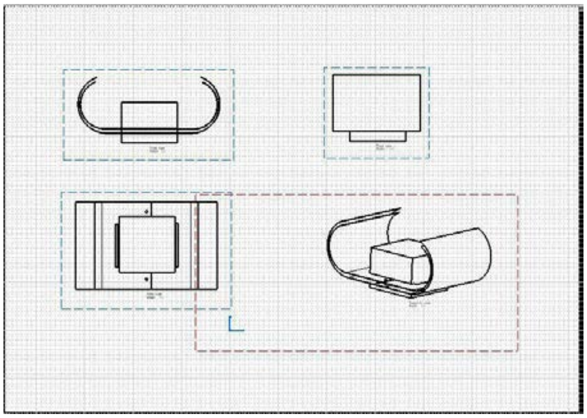


Fig. 2.b: 3D drafted drawing in I angle projection

- The constant voltage range and peak voltage output were noted for all thicknesses with one piezoelectric film attached to the thin-cantilever shell. By this we could identify the thickness at which the performance with regards to constant voltage output was good and could harness vibrations with maximum benefits.
- The particular shell of this optimized thickness was used for further experiments and studies. All the voltages were obtained in the form of alternating voltage values.

- Later, 5 piezoelectric films were coupled together in a series connection and mounted on the thin-cantilever shell of the optimum thickness. Experimental results were noted down.
- Further, the output of the piezoelectric films was connected via cable to the laptop and a software (Sound Card Oscilloscope) was used to read out the voltages with respect to time. These graphs were saved and used for further analysis.
- Vibration testing was done using the Vibration Meter Model: VM-6360 (MEXTECH ™ INSTRUMENTS OF TOMORROW). Displacements, velocities and accelerations were found with two different testing scenarios. First, the meter was attached directly to the engine and values were noted. Secondly, the meter was attached to the tip of thin-cantilever shell and output was recorded.
- Filters were introduced at the piezoelectric output and then the resulting characteristics were recorded using the same software. Voltage outputs for low pass, high pass and band pass filters were also recorded.
- The bode plots for the low pass, high pass and band pass filter outputs - connected to the piezoelectric film output will be displayed and its implications will be discussed. A detailed analysis of the plots is beyond the scope of this work.

The output of this energy harnessing device with a structure and smart materials could be fed into step up transformer or directly processed through a Bridge Rectifier which converts the alternating voltage into direct voltage - which could be used to charge a capacitor or a rechargeable battery. A block diagram of this has been given below.

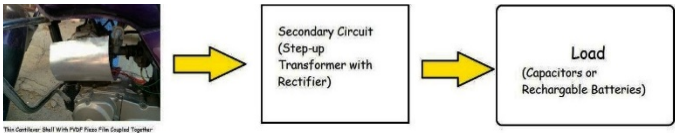


Fig. 2.c: Block diagram of the energy harnessing device

Table 1: Details of the thin cantilever shell

Type	Parameter	Value
Thin cantilever shell	Width	180mm
	Thickness(optimum)	0.5mm
	Density	2715 Kg/m^3
	Young's Modulus	70×10^9 Pa
	Weight	1.4715 N

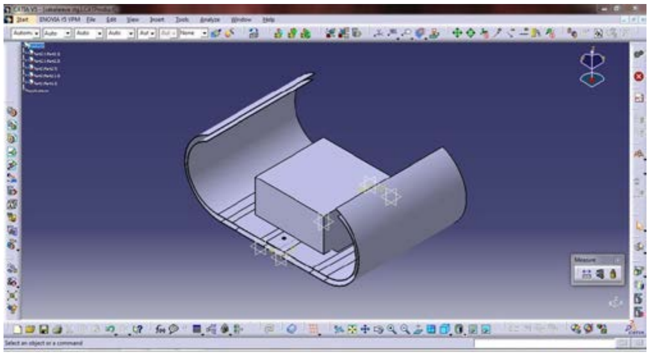


Fig. 2.d: Isometric view of the model designed in CATIA

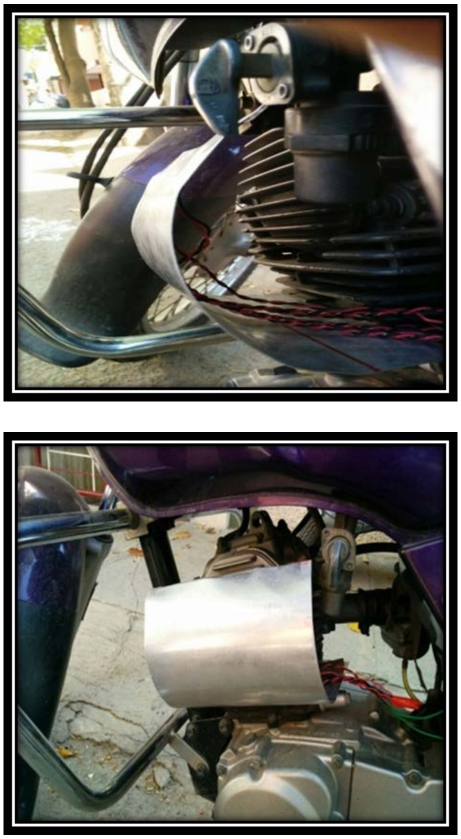


Fig. 2.e: Photographs taken during testing

3. RESULTS AND ANALYSIS

The constant voltage range and peak voltage output was noted for all the thicknesses with one piezoelectric film attached to the thin-cantilever shell. The tables given below with the graphs were critical for the further analysis of the results.

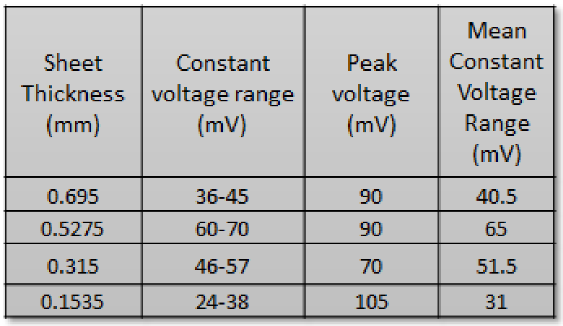
Details of the tests

- Source of vibration: TVS Victor 110cc Motorcycle (2007 model)

- The vehicle was run on an average velocity of 40 km/h.
- The surface condition was that of a normal bituminous road.
- The boundary conditions of the bolted joint were assumed to be hinged.

3.1 Testing results for the device with varying thickness using one Piezoelectric Displacement film

Table 2: Variation of voltage output with change in thickness



Sheet Thickness (mm)	Constant voltage range (mV)	Peak voltage (mV)	Mean Constant Voltage Range (mV)
0.695	36-45	90	40.5
0.5275	60-70	90	65
0.315	46-57	70	51.5
0.1535	24-38	105	31

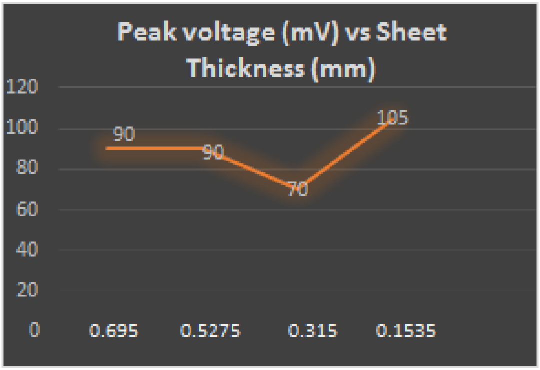


Fig. 3.a: Graph of Peak voltage v/s sheet thickness

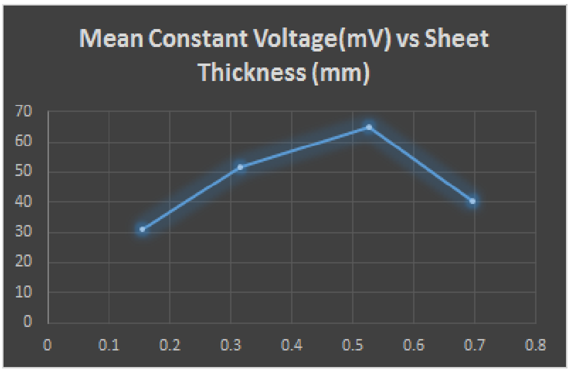


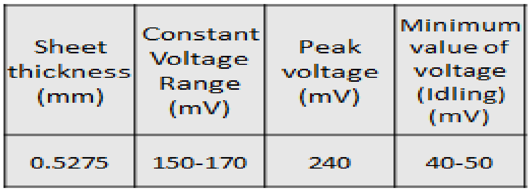
Fig. 3.b: Graph of Mean Constant voltage v/s Sheet thickness

The above graphs show variation of Peak voltage and Mean constant voltage output with respect to the thickness parameter.

3.2 Voltage output for optimum thickness using 5 Piezoelectric Displacement Film

The optimum thickness of the thin-cantilever shell found from previous results was used with coupling of 5 piezoelectric films to enhance the output.

Table 3 Voltages at optimum thickness of Al sheet

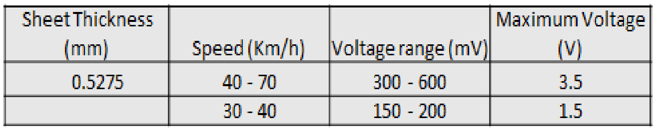


Sheet thickness (mm)	Constant Voltage Range (mV)	Peak voltage (mV)	Minimum value of voltage (Idling) (mV)
0.5275	150-170	240	40-50

Voltage at peak acceleration at Neutral gear: 110mV

With the same apparatus the vehicle was driven on smooth highway roads. The results when the vehicle was at certain speed ranges were recorded. These were recorded when the vehicle was in the 4th gear. They are tabulated below.

Table 4: Voltages of the model at various speeds



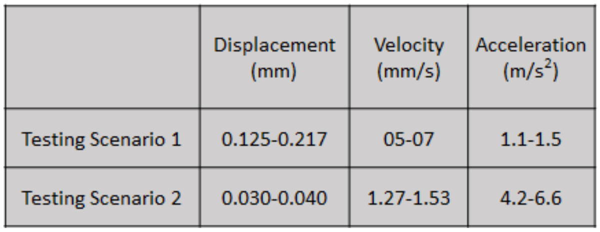
Sheet Thickness (mm)	Speed (Km/h)	Voltage range (mV)	Maximum Voltage (V)
0.5275	40 - 70	300 - 600	3.5
	30 - 40	150 - 200	1.5

3.3Vibration testing

Vibration testing was done using the Vibration Meter Model: VM-6360 (MEXTECH ™ INSTRUMENTS OF TOMORROW) and displacements, velocity and accelerations were found with testing scenario two.

- Testing scenario 1: Accelerometer attached to the thin-cantilever shell tip. Vehicle was in idling condition and at neutral gear without damping by human contact.
- Testing scenario 2: Accelerometer attached directly to the engine where the thin-cantilever shell was in contact with it.

Table 5: Vibration testing results



	Displacement (mm)	Velocity (mm/s)	Acceleration (m/s^2)
Testing Scenario 1	0.125-0.217	05-07	1.1-1.5
Testing Scenario 2	0.030-0.040	1.27-1.53	4.2-6.6

The displacements, when the vibration testing apparatus was connected to the engine were very low and increase at the tip of the thin-cantilever shell when attached to the engine.

3.4 Graphs at Neutral gear and at idling

The voltage outputs were a result of the strain caused by the various forces acting on the thin-cantilever shell. Filters were introduced at the piezoelectric output and then the resulting characteristics were recorded using the software. Voltage outputs for low pass, high pass and band pass filters were also recorded using the Soundcard Oscilloscope software.

The low-pass and high-pass filters when connected showed a lot of variation due to reasons of damping by the thin-cantilever shell structure and changes in driving forces. The graphs were recorded when the vehicle was stationary and placed on the center stand as support and gear kept at neutral position, with filters attached to the output of the piezoelectric film. This was necessary to find the range of frequencies in which the voltage output would be constant.

Voltage output against Time graphs

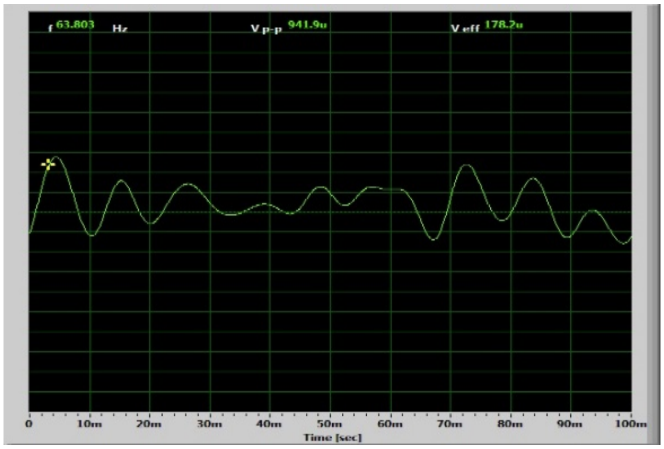


Fig. 3.4.a: Graph of Piezoelectric film output with low-pass filter with higher cut-off of 500Hz

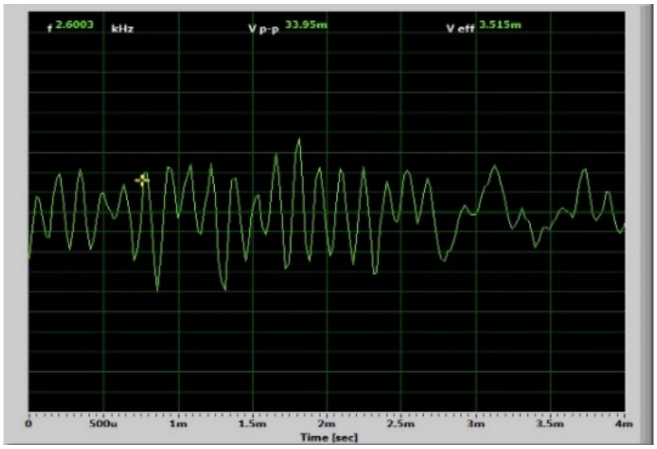


Fig. 3.4.b Graph of Piezoelectric film output with high-pass filter with lower cut-off with 1 kHz

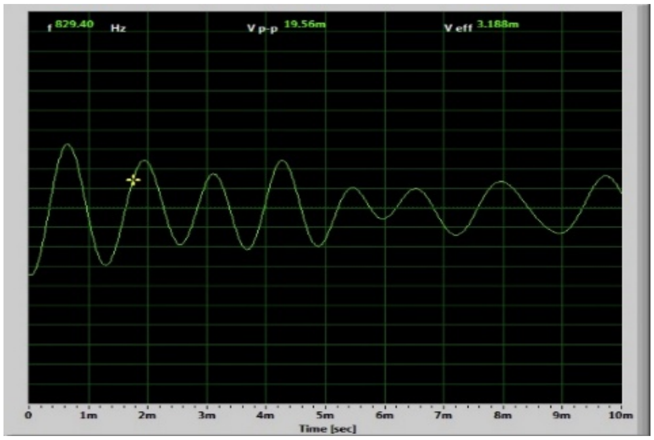
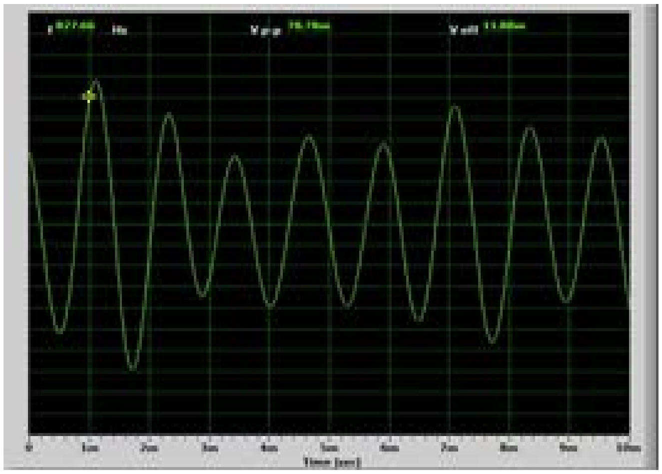
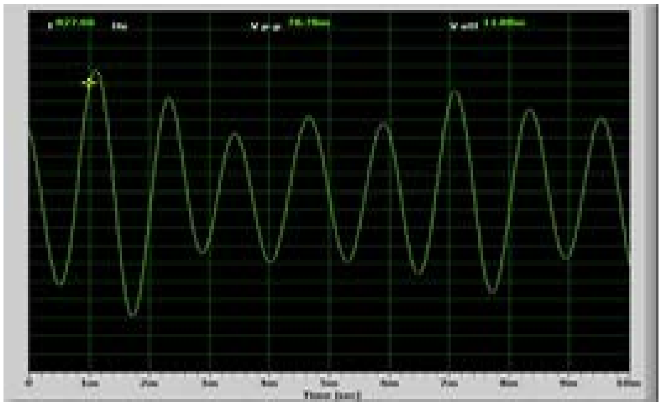


Fig. 3.4.c: Graphs of piezoelectric film output with band-pass filter with lower cut-off of 500Hz and higher cut-off of 1 KHz





It can be observed that the voltage against time graph, when a band-pass filter was connected to the output with cut-off frequencies ranging from 500-1k Hz gave a more promising output with voltage being almost with in a constant range.

3.5 Frequency response

BODE PLOT

The frequency response graphs without filters were provided to demonstrate the randomness of the vibration that will be dealt with.

The graphs given below are of engine vibrations without filters

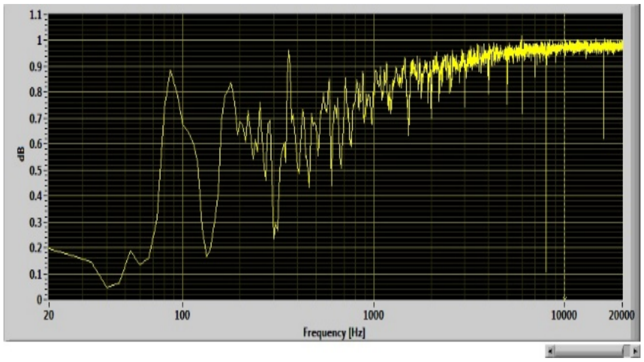


Fig. 3.5.a: Graph of frequency response (without filter)

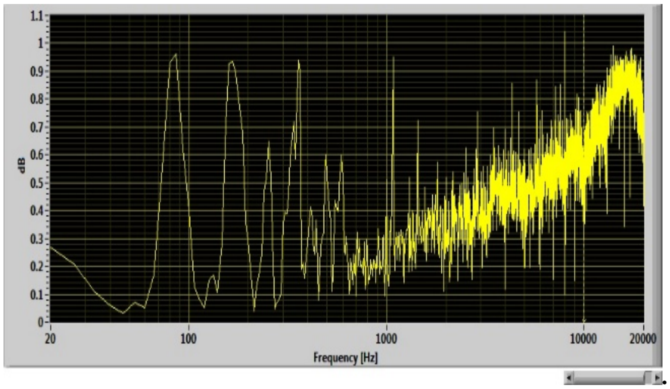


Fig. 3.5.b: Graph of frequency response (without filter)

Bode plot for output with low-pass filter with higher cut-off of 500HZ

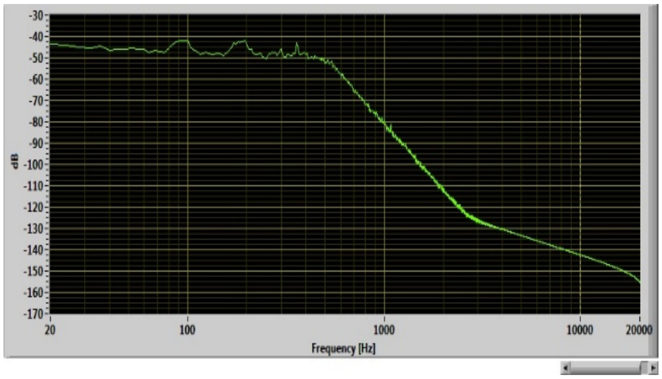


Fig. 3.5.c: Graph of frequency response (without filter)

Bode plot for output with high-pass filter with lower cut-off with 1 KHZ

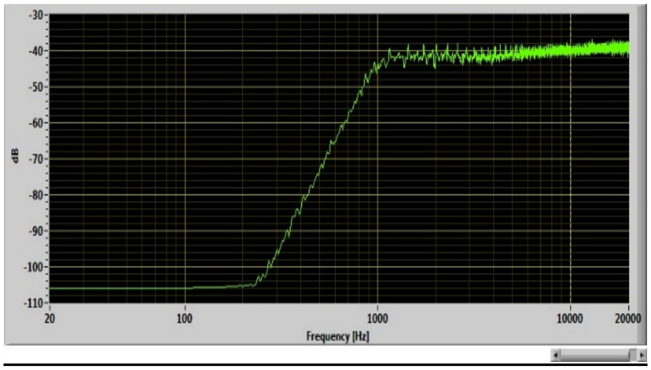


Fig. 3.5.d: Graph of Frequency response with high pass filter

Bode plot for output with band-pass filter with lower cut off of 500Hz and higher cut off of 1 KHz

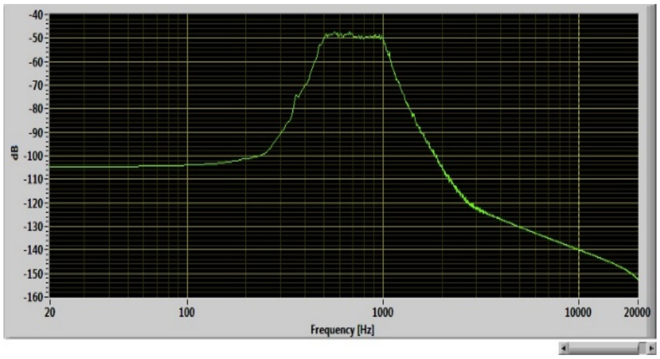


Fig. 3.5.e: Graph of Frequency response graphs with band pass filter

In normal conditions of working the filters have a property of restricting the frequency range to a certain upper and lower limit and power is transferred through the filters only in these ranges. Thus the characteristics got above show proper and expected response from the filters connected and the power transmitted with in the set range of frequency.

4. INFERENCES

The above results were all obtained in random vibration condition, where the motion is non-deterministic, that means the future behaviour cannot be precisely predicted. The randomness was dependent on the input or excitations. Most of the machine vibrations come under this category and harnessing energy from them is a tough task. From the results we have found, thin-cantilever shell performs well in amplifying the displacements and the piezo films also perform reasonably well. The experimental voltage outputs for 5 piezos were obtained (with reference to table 3)

5. CONCLUSION

The designed and fabricated Aluminium thin-cantilever shell with varying thickness was subjected to random vibrations of the light motor vehicle engine and the results showed that, for a sheet of thickness of 0.5275mm, a comprehensive constant voltage output was obtained. When the vehicle was driven on highway roads with speeds ranging from 40-70km/h a constant set of voltage output ranging from 300-600mV was generated. The voltage against time graphs along with frequency response indicating bode plot are crucial in analyzing the future scope of this work. A direct consequence of the increased usage of machines is the augmented availability of vibrational energy. The aim of this work was to provide an alternative source of energy for posterity. Energy saved is energy gained. So the energy harnessed, though small in magnitude, will help us in further Research and Development – thus giving a small solution to the extant energy crisis scenario.

REFRENCES

[1] United Nations Organisation website “http://www.un.org/News/Press/docs/2005/pop918.doc.htm”

[2] International Energy Outlook 2013 (IEO2013) “http://www.eia.gov/forecasts/ieo/”

[3] E. Minazara, D. Vasic and F. Costa, “Piezoelectric Generator Harvesting Bike Vibrations Energy to Supply Portable Devices”, Proceedings of International Conference on Renewable Energies and Power Quality (ICREPQ’08), Santander, Spain, SATIE (CNRS UMR 8029), PRES UNIVERSUD, ENS Cachan, 61 av. du Président Wilson 94230 Cachan, France, 12/3/2008, pg.no. 12-14.

[4] Hausler, E. and Stein, L. “Implantable Physiological Power Supply with PVDF” Film. Ferro electronics, Vol. 60, 1984, pp. 277-282.

[5] Kasyap, A., et al. “Energy Reclamation from a Vibrating Piezoceramic Composite Beam. Ninth International Congress on Sound and Vibration, ICSV9.”

[6] Gonzalez, J., Rubio, A., and Moll, F. A Prospect on the Use of Piezoelectric Effect to Supply Power to Wearable Electronic Devices.

[7] Crawley, E.F., de Luis, J. Use of Piezoelectric Actuators as Elements of Intelligent Structures. Present as Paper 86-0878 at the AIAA/ASME/ASCE/AHS Active Structures, Structural Dynamics and Materials Conference, San Antonio, TX, May 19-21, 1986.

[8] Dimitriadis, E.K., Fuller, C. R., and Rogers, C. A. Piezoelectric Actuators for Distributed Vibration Excitation of Thin Plates. Journal of Vibrations and Acoustics, Vol. 113, January 1991, pp.100-107.

[9] Wang, X., Ehlers, C., and Neitzel, M. An analytical investigation of static models of piezoelectric patches attached to beams and plates. Smart Materials and Structures, Vol. 6, 1997, pp.204-213.

[10] Timothy Eggborn, “Analytical Models to Predict Power Harvesting with Piezoelectric Materials”, Thesis submitted in partial fulfilment of Master of Science, Virginia Polytechnic Institute and State University, Blacksburg, Virginia, May 2003.

[11] Technical Manual, “Piezo Film Sensors”, Measurements Specialities, Inc. Sensor products Division.

[12] Leonard Meirovitch, “Fundamentals of Vibrations”, McGraw-Hill, 2001,ISBN 0-07- 041345-2

[13] S.Timosenko, “Vibration Problems in Engineering”, New York D.Van Nostrand Company, Inc., 1937.