Study of Energy Harvester for Vibration Absorbtion

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***Abstract*— Electricity is the greatest crisis in the world on one side and another side is environmental pollution is caused by E-waste especially due to smart devices such as mobile phones, laptops, compact devices, computer spare parts, unrecyclable batteries etc. By considering these problems authors are taken up a research on energy harvesting by using ambient vibrations. In this field so far people had done a lot of research only by using clamped-free beam with tip mass for dynamic flexibility. In this paper the authors are demonstrating the novel energy harvester cram by using clamp-free beam with impact mass harvester as a tip mass. Here impact mass harvester is fulfilled the both purposes one is for generating electricity and the another one is for dynamic flexibility by absorbing vibrations. The mass of 9 grams lead material is considered as a hitting mass on Lead Zirconate Titanate (PZT) patch and developed a voltage of 45.25 V is on average and 98 V is the maximum as an output at the resonance frequency of 82.231Hz for charging the impulse power applications.**

Keywords*— Energy harvester; Vibration absorber; Clamped free beam.

INTRODUCTION

Vibration energy harvesting is defined as the harvesting or scavenging electrical energy from vibrations which are available naturally or by using some means[1]. Whereas Piezoelectricity is a form of coupling between the mechanical and the electrical behaviours of ceramics and crystals belonging to certain classes. These materials exhibit the piezoelectric effect , which is historically divided into two phenomena as the direct and the converse piezoelectric effects. When a piezoelectric material is mechanically strained , electric polarization that is proportional to the applied strain is produced. This is called the direct piezoelectric effect and it was discovered by the Curie brothers in 1880.When the same material is subjected to an electric polarization , it becomes strained and the amount of strain is proportional to the polarizing field[2]. This is called the converse piezoelectric effect or inverse piezoelectric effect. Representative piezoelectric materials can be categorized into piezoceramics and piezopolymers. Piezoceramics have large electro-mechanical coupling constants and provide high energy conversion rate, but they are too brittle to use general shape energy transducer. On the other hand, piezopolymers have smaller electromechanical coupling constants compared to the piezoceramics, but they are very flexible[3]. Based on direct piezoelectricity, many research works have been conducted for piezoelectric energy harvesting from mechanical vibration. Piezoelectricity is found in useful applications such as the production and detection of sound, generation of high voltages, electronic frequency generation, microbalances, and ultrafine focusing of optical assemblies. Although the magnitudes of piezoelectric voltages, movements, or forces are small, and often require amplification, piezoelectric materials have been adapted to an impressive range of applications [4]. The piezoelectric effect is used in sensing applications, such as in force or displacement sensors. The inverse piezoelectric effect is used in actuation applications, such as in motors and devices that precisely control positioning, and in generating sonic and ultrasonic signals. In the 20th century metal oxide-based piezoelectric ceramics and other man-made materials enabled designers to employ the piezoelectric effect and the inverse piezoelectric effect in many new applications. These materials generally are physically strong and chemically inert, and they are relatively inexpensive to manufacture. The composition, shape, and dimensions of a piezoelectric ceramic element can be tailored to meet the requirements of a specific purpose. Ceramics manufactured from formulations of lead zirconate / lead titanate exhibit greater sensitivity and higher operating temperatures, relative to ceramics of other compositions, and PZT materials currently are the most widely used piezoelectric ceramics. Piezo-electrics are the most popular materials. They undergo surface elongation (strain) when an electric field is applied across them (actuator characteristics); produce voltage when surface strain is applied (Sensor characteristics), and thus can be used both as actuators and sensors. Under applied field, these materials however generate very low strain but cover a wide range of actuation frequency; this makes them to be used in vibration control. The most widely used piezoceramics (such as lead zirconate titanate) are in the form of thin sheets which can be readily embedded, surface bonded or attached to composite structures. There are three issues that limit the broad technological impact of the vibration-based piezoelectric energy harvesters. Firstly, development of high coupling coefficient piezoelectric materials is essential to improve the performance of piezoelectric energy harvesters. Proportional to the coupling coefficient, the energy conversion efficiency will be improved therefore increasing the coupling coefficient for the PZT material is quintessential. Thus, the advent of new piezoelectric materials with high coupling coefficient will bring a new era of piezoelectric energy harvesters. Secondly, the energy harvesters should be able to sustain under impact loads, random vibrations and shocks. Thus, development of flexible and resilient piezoelectric materials is necessary. Thirdly, development of efficient electronic circuitry for energy harvesters is necessary. Since the obtained electrical energy from vibration is small, rectification and energy storing circuits should be able to activate in such a low power condition. Vibrations are available everywhere therefore vibration-based energy harvesters should come to the real life of the world population. Many researchers has done on the clamped free beam by taking tip mass and attached the rectangular PZT 5H patch on the beam but nobody designed the ESD and considered it as dual purpose for dynamic flexibility and generating maximum voltage and also absorbs the vibrations.

Mathematical modeling of Energy harvester (ES)

PZT-5H 5H material having a density of 7600 kg/m^3 , Piezoelectric voltage constant of 24.8x10^{-3} m^2/c, relative dielectric constant of 1900, modulus of elasticity of 6.3x10^{10}N/m^2 , curie temperature is 320^0 C and Piezoelectric charge constant of 400x10^{-12}m/V . we have used the 9 grams lead ball as a impact loader on the PZT-5H 5 H patches during excitation. Lead is having a properties of density is 11.3 g/cm^3, modulus of elasticity as 16 GPa and Poisson ratio as 0.44[5,6].

The displacement of support is

$$y(t) = Y\sin\omega t \qquad (1)$$

$$m\ddot{z}(t) + c\dot{z}(t) + kz(t) = -m\ddot{y}(t) \qquad (2)$$

Solution for under damped case

$$z(t) = Ae^{-\xi\omega_n t}\sin(\sqrt{1-\xi^2}\,\omega_n t + \varphi) + \frac{Y\left(\frac{\omega^2}{\omega_n^2}\right)\sin(\omega t - \varphi)}{\sqrt{\left(1-\frac{\omega^2}{\omega_n^2}\right) + \left(\frac{2\xi\omega}{\omega_n}\right)^2}} \qquad (3)$$

$$\frac{z}{Y} = \frac{\left(\frac{\omega^2}{\omega_n^2}\right)}{\sqrt{\left(1-\frac{\omega^2}{\omega_n^2}\right) + \left(\frac{2\xi\omega}{\omega_n}\right)^2}} \qquad (4)$$

The total power dissipated in the damper under sinusoidal excitation was found to be given below.

$$p(\omega) = \frac{m\xi Y^2\left(\frac{\omega^3}{\omega_n^3}\right)}{\sqrt{\left(1-\frac{\omega^2}{\omega_n^2}\right) + \left(\frac{2\xi\omega}{\omega_n}\right)^2}} \qquad (5)$$

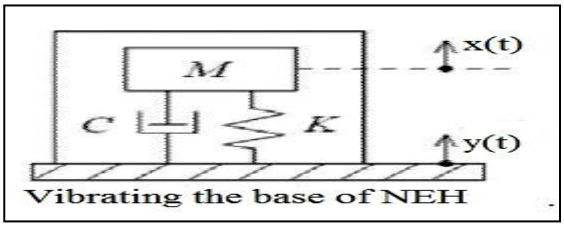

Fig.1. Equivalent mathematical model of EH

Experimental Procedure

The EH is made with two supported plates made of Aluminium, two PZT-5H patches, one PVC striker guide and clamped free beam is shown in figure 2 with dimensions. A lead ball of having a diameter of 10 mm was used for inducing the dynamic strain to the PZT-5H patches. A four bolts 100 mm x 5 mm were used for keeping the EH strongly and not to be damaged when it is under testing on electromagnetic exciter.

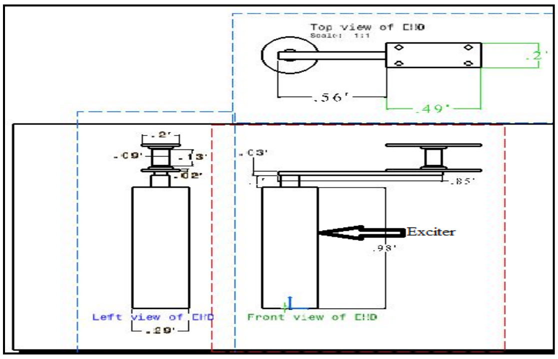

Fig.2. Orthographic views of EH

Fig .3(a). Experimental setup of EH

The distance between two PZT-5H patches positions was 39 mm. The length of the clamped free beam was 315 mm, supporting plates dimensions was 147 mm x 60 mm and the size of PZT-5H patches was 40 mm diameter and 4 mm thickEHs. The piezoelectric elements were manufactured by APC International Limited (catalogue no. 40-1010). The EH was mounted on the 20g electromagnetic exciter and the harmonic excitation was given through amplifier and oscillator at 25 Hz, 30 Hz, 35 Hz, 40 Hz in steps of 5 Hz upto 100 Hz and recorded the output voltage through digital storage oscilloscope. The voltage signal was in sin wave form. Sometimes sine wave is the combination of noise waves. The noise waves can be filtered by using MATLAB tool. A rectifying circuit consists of a 25V(10 mF) capacitor along with four diodes was installed beside the case of the EH to convert the generated AC current to DC. The DC voltage generated would be useful for functioning the low power devcies. The rectifying circuit design was presented in Fig. 3(b)[7] . The complete arrangement of EH and digital storage oscilloscope was shown in figure 3(a).

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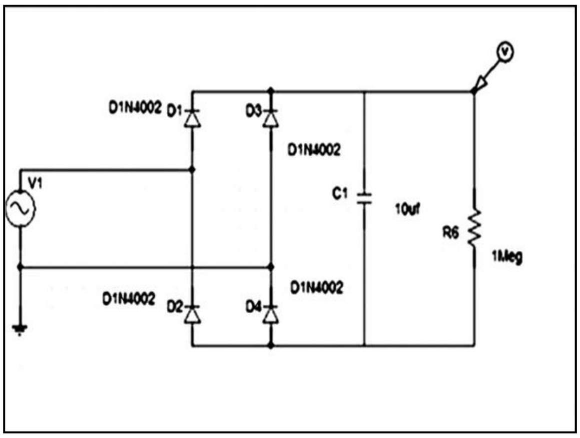

Fig .3(b). Electrical circuit for rectification of EH's output

RESULTS AND DISCUSSION

There are six experiments are conducted by using clamped free beam with ESD at different frequencies such as <20 Hz, 3.543kHz, 82.231 Hz, 73.58 Hz, 91.43 Hz and 79.43 Hz . All DSO readings are shown from Fig.4 to Fig.9. At the resonance frequency the travelling distance of hitting mass will be maximum thus it causes to create maximum dynamic strain (DS) in the PZT patches. When the DS is maximum, the output power from the device is maximum that increases the efficiency of energy harvesting. All the readings are taken at the division per signal is 2 V and the time is 2.5 s but at the frequency of 3.54 kHz, the voltage per division of DSO signal is 50 mV at the time of 2.5 s. GW Instek DSO is used for reading the Voltage Vs Time signal in digital form at different frequencies, the memory length for each signal is 500, Trigger level is zero, source is CH1, vertical units is V, vertical scale is 2 V, vertical position is 2.24, horizontal unit is s and horizontal scale is 2.25. Even though ESD is tested at different frequencies but the discussion is focussed at the resonance frequency of 82.231Hz and its digital signal form as shown in Fig.10. Fig.10 illustrates the operation and behaviour of hitting mass and the PZT patches. The total signal is studied by taking into 392 points on the horizontal scale, at the three points, the generated voltage is maximum related to other points. One is between18 to 35 is around more than 50 V, between 120 to137 is around more than 90 V and closer to point 392, voltage is 80. At remaining points the voltage is 45 V has been maintained constantly. On total average the output is 45.25 V for the frequency of 82.23 Hz.

Fig. 4. DSO reading at 3.54 kHz

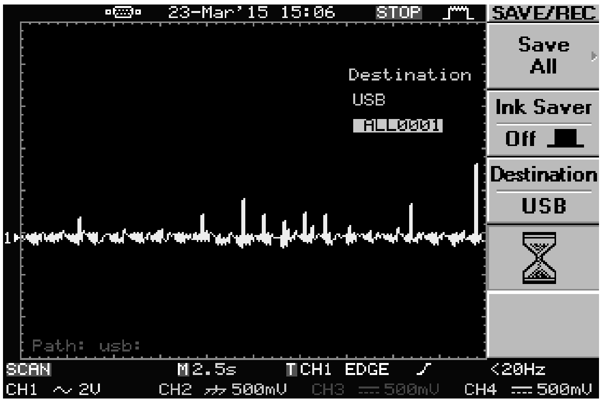

Fig.5. DSO reading at less than 20 Hz

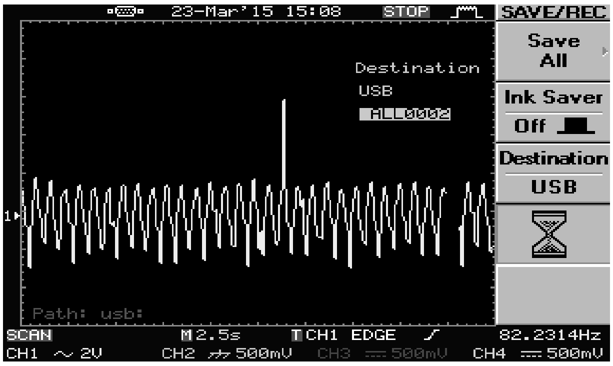

Fig. 6. DSO reading at 82.231 Hz

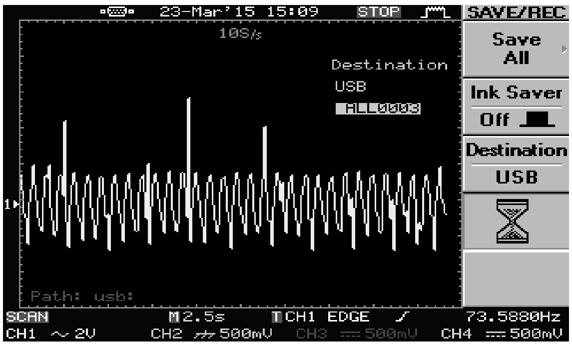

Fig. 7. DSO reading at 73.58 Hz

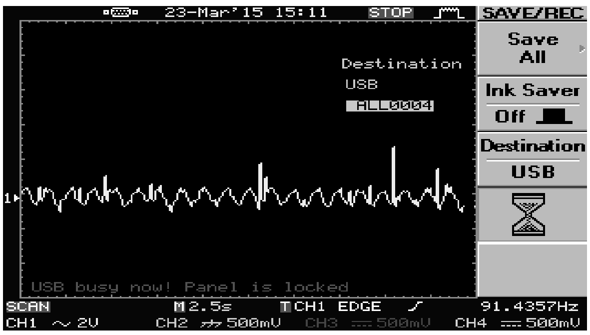

Fig. 8. DSO reading at 91.43 Hz

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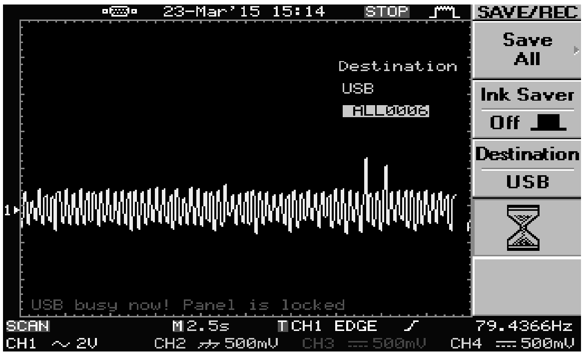

Fig.9. DSO reading at 79.4366 Hz

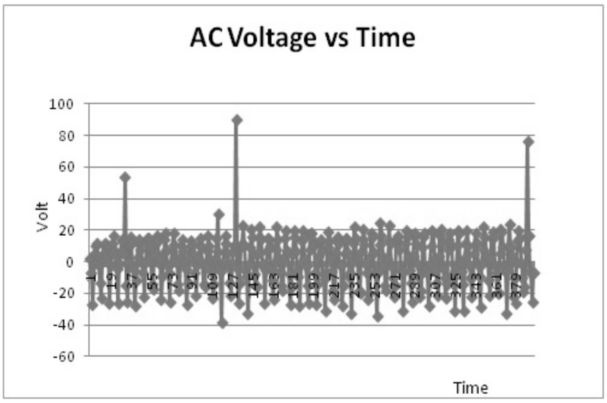

Fig.10. DSO reading at 82.231 Hz in digital form

If ESD is tested directly on the Exciter, at the same frequencies, the output can be maximum based on the principle of Frahm's principle of vibration absorber. Experiments are conducted by using ESD as lumped mass type and the output of maximum voltage is 115 V at the frequency of 82.231 Hz.

CONCLUSION

In this paper clamped free beam with ESD is designed and tested at the frequencies of <20 Hz, 3. 543 kHz, 82.231 Hz, 73.58 Hz, 91.43 Hz and 79.43 Hz and demonstrated the readings of DSO in detail with volt per division and time. In detail explained the results of resonance frequency in digital form and also explained the design of ESD. The generated average voltage is 45.25 V and the maximum voltage is 98 V for charging the low power devices. If the PZT patches are connected in parallel the output current in amps will be maximum.

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