A Piezoelectric Energy Harvester for simultaneous Vibration Isolation and Energy Harvesting

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***Abstract*— A vibration isolator with energy harvesting abilities is presented in this work. The developed device is able to isolate the environment from vibration of appliances such as electrical generators and automobile's engine etc. and convert the vibration to electrical energy. The resulting energy produced from the energy harvester can be used to power the condition monitoring unit The developed device was able to exhibit a resonance at 56 Hz frequency. 1.7 V open circuit voltage was reported for the developed harvester at 2 g acceleration. Moreover, the maximum power delivered to the optimum load of 340 kΩ was 1.1 mW.**

Keywords*— *Damping, Energy harvesting, Low cost fabrication, Piezoelectric, Vibration isolator

I. Introduction

Machine health monitoring is a predictive method, with the help of which the condition of a machine is screened and timely predicted . This technique involves monitoring specific parameters of a machine, such as, temperature, pressure and acceleration. which allow to monitor the machine health and predict the event of breaking down. This monitoring task is accomplished by employing a condition monitoring unit. The condition monitoring unit comprises of a single or multiple sensors which sense the physical condition (sound, temperature, pressure and acceleration) of the machine. The architecture further includes a microcontroller, a signal conditioning unit, a memory card and a power management circuit. The microcontroller performs the task of measuring physical phenomenon by activating the sensor periodically. The sensor's signal is then processed in the signal conditioning unit to extract the desired information. The microcontroller further stores the data in memory card for transmission. This procedure requires power which is provided by the onboard batteries. The problem occurs when batteries are run out of its power and the operation of the condition monitoring unit is compromised and terminated. However, in condition monitors, this batteries problem can be tackled by integrating an energy harvester in the architecture to convert the ambient energy from environment, such as, vibration, thermal, acoustic or solar into electrical power. Moreover, condition monitoring unit's internal components are powered by DC voltage but energy harvesters, normally, produce AC voltage, which is then converted to DC voltage by a voltage AC to DC rectifier [1].

Vibration energy from machines, such as, generators, turbines and automobile engines etc. can be converted to electrical energy by employing electromagnetic [2], piezoelectric [3] or electrostatic [4] energy harvesters.

Work has been done previously to simultaneously absorb vibration and convert it into electrical energy. Energy harvesting mechanical shocks were developed to produce electrical power while performing vibration damping [5]. The resonant frequency of the developed electromagnetic shocks was recorded to be 16.8 Hz, while an internal resistance of 226 Ω was reported for the developed prototype. The fabricated device was observed to produce 8 mV open circuit voltage at 12.5 g rms acceleration. Furthermore, the harvester generated an output power of 35 µW. A hydraulic damper was developed with an integrated energy harvester for extracting energy [6]. When subjected to a vibratory excitation, hydraulic oil flow inside the cylinder was used as a transduction mechanism to power a hydraulic motor. The hydraulic motor was integrated with an electromagnetic generator which was utilized for power production. 2 Ω optimal resistance was reported for the device. 435.1 $W(m/s)^{-1}$ was reported for the fabricated device when subjected to a frequency of 0.8 Hz and an amplitude of 0.02 m.

An electromagnetic power generator was developed as a part of semi-active suspension [7]. The aim was to utilize the available vibration between the wheels and sprung mass and converts it to electrical power. The proposed device produced a power density of 4160 W/m^3, which when subjected to optimization by genetic algorithm was improved to 5307 W/m^3. An energy harvesting vibration isolator with piezoelectric transduction mechanism was developed [8]. The device when subjected to vibrational excitation enables a fluid to flow between the cylinder chambers. The flowing fluid when channeled to a piezoelectric transducer enables it to produce electrical power. The piezo-hydraulic isolator was found capable to deliver an output voltage of 98 V at 19.8 Hz frequency. Vibration between panels as means of harvesting energy and extracting electrical energy while simultaneously damping the vibrations is reported [9]. Circular corrugated Polyvinylidene fluoride (PVDF) springs were designed, developed and were bonded between two PVDF films. The designed device was able to exhibit its resonance frequency of 43 Hz and deliver 13.6 µW output power.

The device presented in this research focuses on converting the vibration energy to electrical energy using piezoelectric technique. Piezoelectric material falls under the category of smart materials which responds to a stimulus from the environment by changing its color, shape, viscosity etc. In the case to the piezoelectric material the external stimulus is pressure (deflection) and the response is producing an electrical charge [10].

The piezoelectric material has a number of non-symmetric atoms arrangement resulting in formation of electric dipole moments. When stress or strain is not being applied on the piezoelectric material the electric dipole moments cancel each other and no voltage is produced. However, when the material is subjected to stress the electric dipole moments align producing a positive charge on one side and a negative charge is produced on the other side. This charge formation is responsible for voltage induction in piezoelectric material.

In this work a vibration damper is developed which could not only damp and isolate the vibration of the machine but also will generate electrical energy to power the wireless sensors. In the device a unimorph piezoelectric circular plate is embedded in a silicone to form a cylindrical vibration damper or isolator.

II. ARCHITECTURE AND FABRICATION

The architecture of the energy harvesting piezoelectric vibration isolator consists of a unimorph piezoelectric circular disc that is embedded in the silicone cylindrical structure. Fig. 1 (a), shows the cross-sectional view, however, fig. 1 (b), depicts the exploded view of the device. A unimorph 'PZT-5H' material deposited on a circular brass plate was used in the device with d_{33} mode. The device absorbs vibrations due to the resilient nature of silicone, while some of the vibrations are experienced by the piezoelectric deposited brass plate. The vibration experienced by the piezoelectric material causes the dipoles in it to align and induce a voltage across the terminals.

The energy harvesting piezoelectric vibration isolator is fabricated with a room temperature vulcanization silicone. A unimorph piezoelectric plate with 0.2 mm thickness and 14 mm diameter was chosen. Fig. 2 shows the fabrication steps during the device production. Fig. 2 (a) shows the piezoelectric plate to which electrical wires are soldered, fig. 2 (b) shows the step in which the piezoelectric plate was dipped in an uncured silicone with the help of a plastic syringe. The whole structure was then cured for three days. The cured silicone structure was extricated out of the container using a plunger inside it. Fig. 2 (c) shows the cured silicon structure with piezoelectric plate embedded inside. Fig 2 (d) shows the finished harvester after unwanted silicone was eliminated.

III. EXPERIMENTATION AND RESULTS

Fig. 3 depicts the block diagram developed for characterizing the developed device. The fabricated test setup involved an inverted vibration shaker with aluminum stand for incorporating the energy harvesting piezoelectric vibration isolator. The vibration shaker is integrated with a power amplifier Rock Mars RM AT 3600 [11]. The input to the setup was provided by a function generator [12]. To find the acceleration an accelerometer ADXL 335 [13] was fixed to the Teflon cylinder mounted on the shaker table. The output from the energy harvesting piezoelectric vibration isolator and the accelerometer was fed to the oscilloscope [14] and examined.

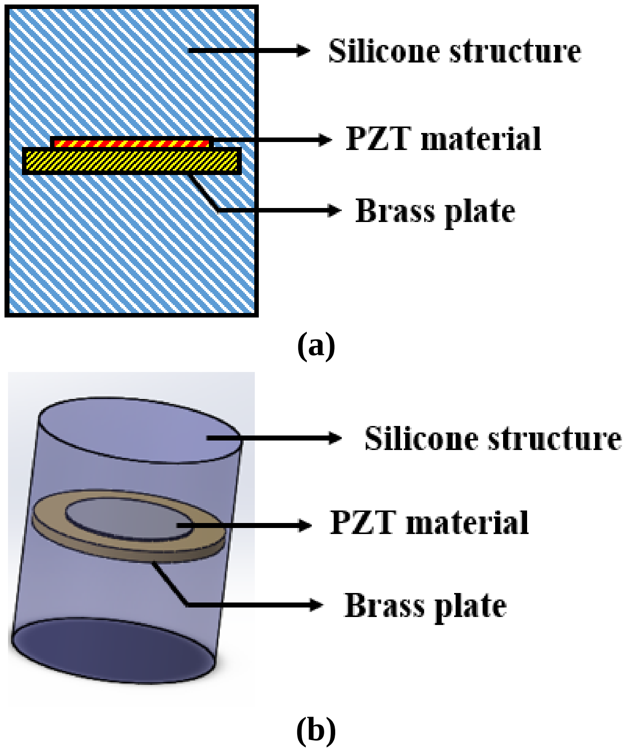

Fig. 1. Energy harvesting piezoelectric vibration isolator (a) Cross-sectional view (b) 3D model

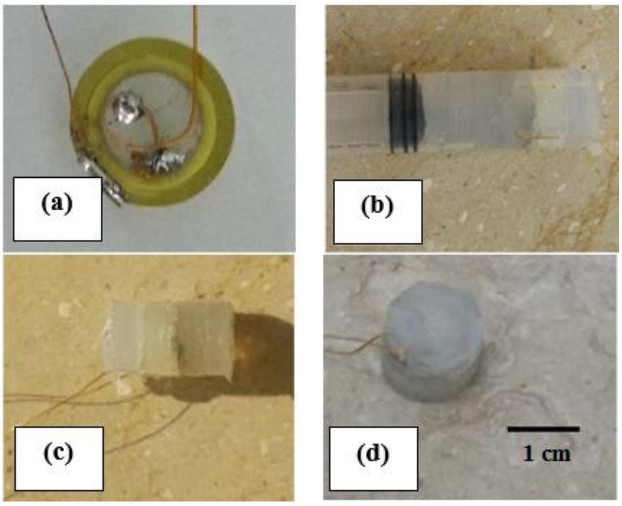

Fig. 2. Energy harvesting piezoelectric vibration isolator fabrication steps (a) Unimorph piezoelectric plate (b) Piezoelectric material deposited plate embedded in uncured silicone (c) Cured silicone structure (d) Finished energy harvester

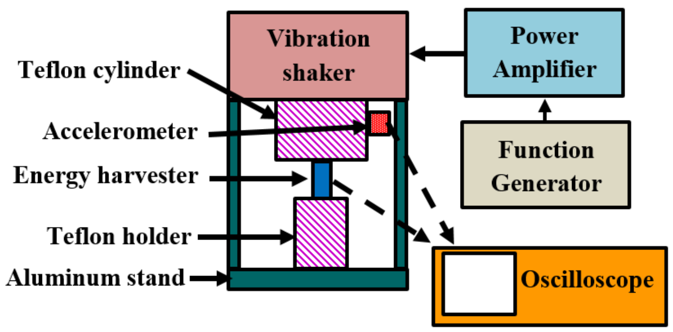

Fig. 3. Schematic of testing setup developed for the testing of energy harvesting vibration isolator

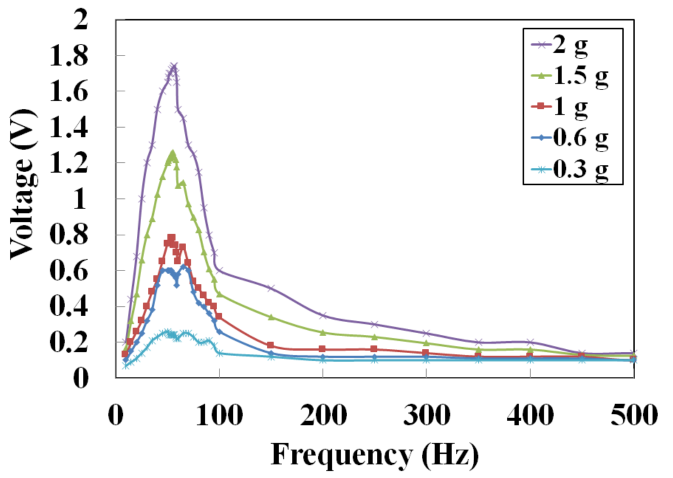

Fig. 4. Frequency versus voltage response of energy harvesting piezoelectric vibration isolator

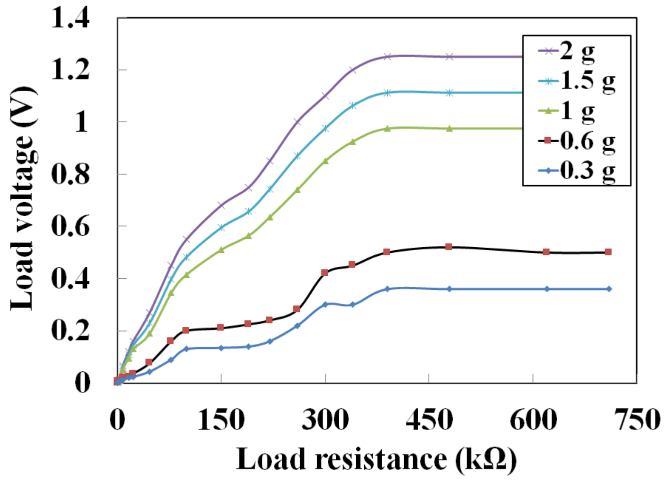

Fig. 5. Load voltage versus load resistance at different acceleration levels

Fig. 4 depicts the frequency versus output voltage of the harvester. The energy harvesting piezoelectric vibration isolator was characterized at different acceleration levels ranging from 0.3 g to 2 g. The harvester was subjected to a frequency sweep from 10 to 500 Hz. At lower acceleration levels of 0.3, 0.6 and 1g a resonant frequency of 55 Hz was recorded for the device. However the resonance frequency tends to shift to 56 Hz when subjected to higher acceleration levels, such as, 1.5 and 2 g. The energy harvesting piezoelectric vibration isolator was able to produce an open circuit voltage of 240, 600 and 780 mV at acceleration levels of 0.3, 0.6 and 1g respectively. Furthermore at acceleration levels of 1.5 and 2 g the device reported 1235 mV and 1745 mV open circuit voltage respectively.

Fig. 5 depicts load resistance versus load voltage plot. To conduct this experiment the energy harvesting piezoelectric vibration isolator was vibrated at its natural frequency and was tested with different acceleration values and load resistors ranging from 560 to 710 kΩ were connected to the harvester. A change in load voltage was observed for load resistances ranging from 560 to 340 kΩ. However, beyond 340 kΩ the load voltage became almost constant.

Fig. 6 represents the load power as a function of load resistance. The power was calculated from the data acquired from the load voltage and load resistance readings. From fig. 6 it was concluded that 2.1 mW power was achieved at an optimum load resistance of 340 kΩ.

The energy harvesting piezoelectric vibration isolator was also merged with AC to DC rectification unit. The AC from device was converted to DC employing a wheat stone bridge rectifier [16]. Fig. 7 shows the schematic of the wheat stone bridge rectifying circuit. The rectification was performed with a 470 µF capacitor and 1N4007 diodes. Fig. 8, shows the AC input from the energy harvesting piezoelectric vibration isolator and the DC voltage after rectification. The AC voltage from energy harvesting piezoelectric vibration isolator was successfully rectified to 2 V DC.

The damping ratios were also found for the energy harvesting piezoelectric vibration isolator utilizing the logarithmic decrement method. Open circuit and optimum load damping results are elaborated in Fig. 9. An increase in damping was observed when the device was integrated with optimum load due to the inclusion of electrical damping. For the open circuit the damping ratio of 0.012 was observed, however the optimum load damping was reported to be 0.025.

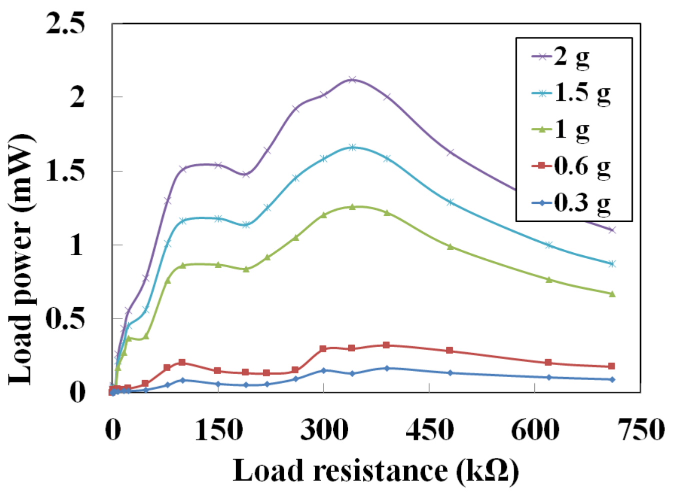

Fig. 6. Load power versus load resistance at different acceleration levels

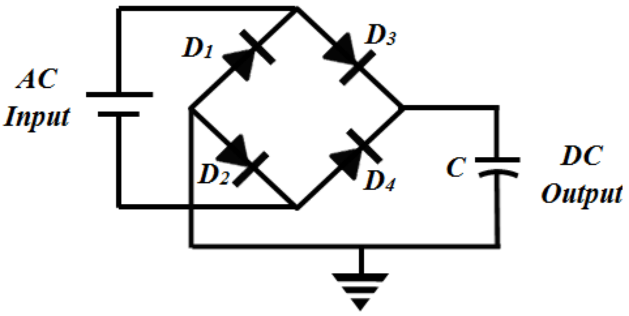

Fig. 7. Schematic of Wheat Stone Bridge Rectifier

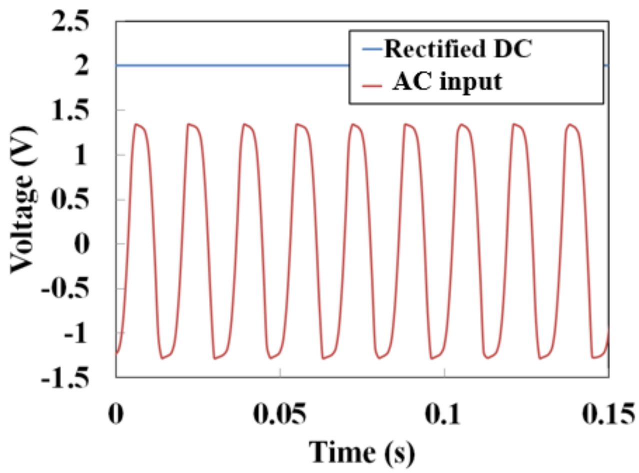

Fig. 8. AC Input from the energy harvesting piezoelectric vibration isolator and rectified DC voltage

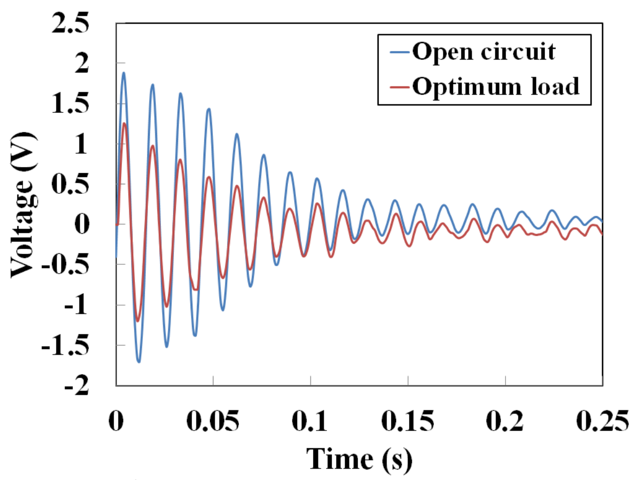

Fig. 9. Device free vibration response with open circuit and optimum load

IV. CONCLUSION

An energy harvesting device was developed with ability to be used as vibration isolator. A low cost fabrication technique was also developed for the energy harvesting piezoelectric vibration isolator with room temperature vulcanization silicone. The prototype device was tested successfully in the lab at different frequencies and acceleration levels. The energy harvesting isolator recorded an open circuit voltage of 1.73 V at a resonant frequency of 56 Hz and acceleration of 2 g. Furthermore, the device was also tested to find the maximum output power using maximum power transfer theorem. The device was found capable of providing an output power of 1.1 mW. The developed energy harvesting piezoelectric vibration isolator was also integrated to a voltage rectification circuitry to convert the resulting AC to DC voltage. The rectified DC voltage was found sufficient to run low power wireless sensors. Moreover, the device's damping ratio at open circuit and optimum load was found to be 0.012 and 0.025 respectively.

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