Review of Wide-Frequency Bandwidth Piezoelectric Vibration Energy Harvester

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Abstract

Piezoelectric energy harvester have been as an alternative source of renewable energy. Due to the low energy generated by the harvester, current progress of research in piezoelectric vibration energy harvester are focusing on optimizing the output power while increasing the frequency bandwidth enabling the harvester to scavenging the mechanical vibration effectively. This paper summarize some of current progress with regard the methodologies to increase the frequency bandwidth of the harvester.

Keywords - *piezoelectric, frequency bandwidth, generator*

I. INTRODUCTION

In this current generation, humans have been facing energy crisis. Humans have been using renewable energies such as biomass, hydropower, solar power, geothermal power. The problem with renewable energy is, it always depends on the situation. Even though it can be replenished within a certain amount of time, depending on renewable energies can be tough as it is not easy to maintain and it varies with every countries natural resources. Depending on renewable energy will not be sufficient enough to power up the current world energy demand. As time goes, the demand for energy keeps on rising thus finding a new source of energy is vital. Thus, my research will study on the effects of wide-frequency bandwidth energy harvester using piezoelectric which works by converting mechanical vibration into electrical voltage. The research will benefit humans in a major scale of energy conservation for the future usage.

II. PIEZOELECTRIC ENERGY HARVRESTERS

Sharvari Dhote et al (2018) have worked on the usage of magnetic force to enhance the performance of a compliant orthoplanar spring piezoelectric vibration based energy harvester (COPS-PVEH). This energy harvester is able to improve the performance in terms of a wider bandwidth and a high voltage output. The magnet is added to the spring of the COPS-PVEH in order to manipulate the harvester systems stiffness. The experiment is conducted by adding a moving magnet at the center of the spring and a pair of fixed magnets at the top and bottom sides of the harvester. The simulation results are obtained by using MATLAB. For the experimental setup, the energy harvester is mounted on a shaker which provides a base excitation. A laser Dopple Vibrometer is used to measure center mass velocity of the springs using the oscilloscope. The oscilloscope connected to the energy harvester acquired and records the voltage-frequency data. Through experiment conducted, it is found that by adding magnetic force, there is an increase in the bandwidth and an increase in the voltage output. The experiment is manipulated by using multiple masses and it is proven that this additional masses increases the voltage output and bandwidth.

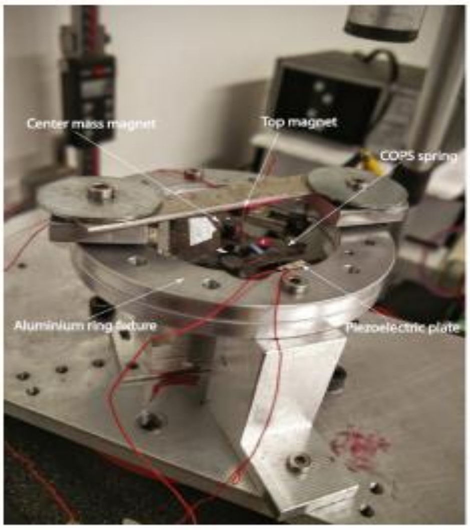


Fig. 1: COPS-PVEH prototype harvester with magnets [1]

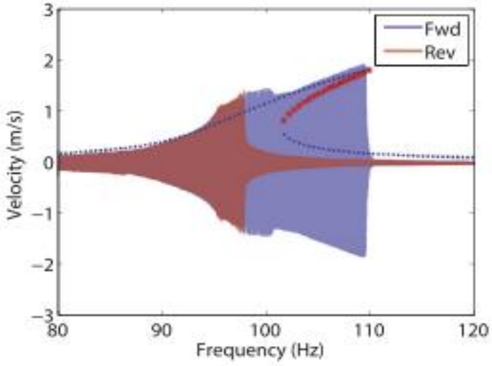


Fig. 2: Velocity-frequency responses of the COPS-PVEH during forward and reverse sweeps with magnets. [1]

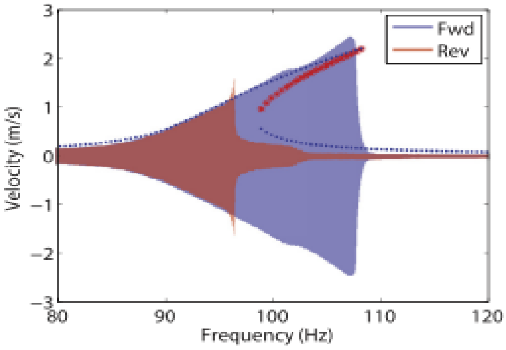


Fig. 3: Velocity-frequency responses of the COPS-PVEH during forward and reverse sweeps without magnets. [1]

Viswanath Allamraju and Srikanth Korla (2015) have designed a spring comprised piezoelectric energy harvester (SPEG). The purpose of this research is to get maximum voltage and power output. This research investigates on a spring added to a piezoelectric energy harvester. The spring is attached to the piezoelectric energy harvester with hitting masses. This setup is capable of harvesting energy from ambient vibrations. The parameters involved in this experiment are length, diameter and mass of shell and hitting mass. By designing the parameters, energy generated is increased. The manipulated variables are stiffness of spring, damping coefficient and the mass of battery. All the analysis is done by using SIMULINK. Based on the simulation, by increasing the stiffness of spring, the amplitude of oscillation also increases linearly. By experiment, the support excitation displacement is changed to study the response of the shell. The voltage produced is measured using BK precision oscilloscope. From the analysis done, it is observed that by maximizing the stiffness and reducing the damping force, time of vibration increases. This in turn increases the voltage and power produced.

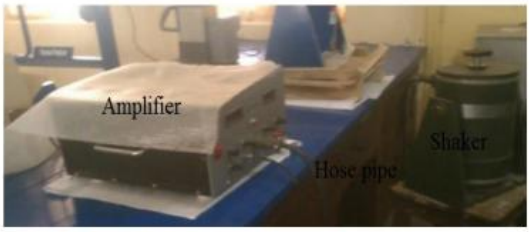


Fig. 4: Experimental setup of shaker with SPEG [2]

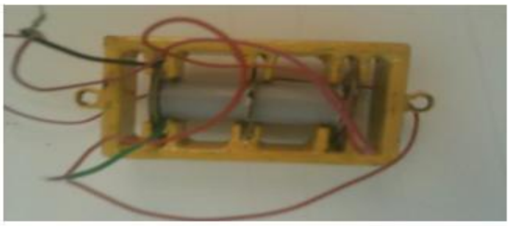


Fig. 5: Shell with piezo actuators with hitting masses [2]

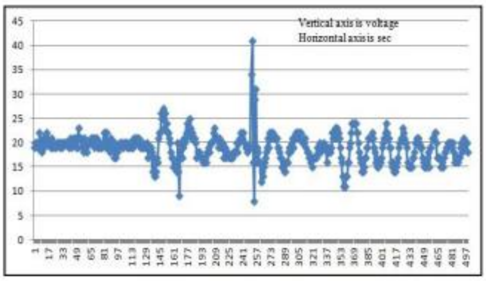


Fig. 6: Oscilloscope reading [2]

Arnaud Notué Kadjie and Paul Woafo (2014) have conducted a study on a model of energy harvester that consists of an electromechanical pendulum system subjected to nonlinear springs. The number of springs are manipulated in order to investigate on the output power produced. The controlled variables in this research are the frequency and amplitude of the external excitation, the load resistance, the number of coil turns, the magnetic induction, the rod length and the spring stiffness is kept constant. Two permanent magnets are placed to produce a constant magnetic induction. Two springs are attached to the rod carrying the proof mass. It is found that the inclusion of two springs on the pendulum arm increases the value of power attained compared to no springs attached.

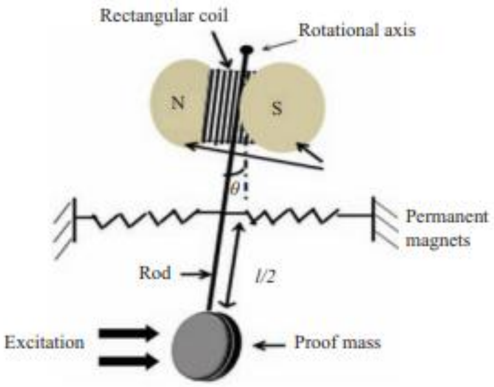


Fig. 7: Pendulum energy harvester model schematic diagram [3]

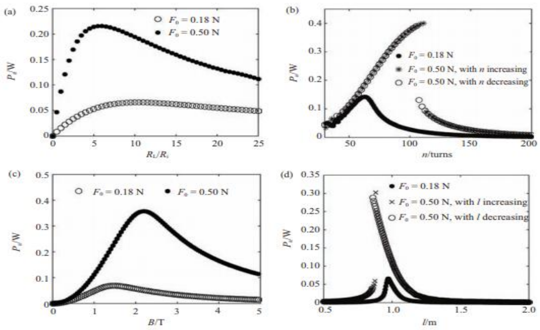


Fig. 8: Average power in the load as a function of (a) RL/Ri, (b) number n of the coil turns, (c) magnetic induction, (d) rod length [3]

Koki Yamamoto et al (2015) have researched on a design improvement of combination spring that consists of a linear resonator and a curved beam for nonlinear vibration energy harvester. The curved beam acts as a mechanical frequency converter (MFC). It applies high frequency acceleration to the linear resonator. By using a parallel curved beam, buckling beam with low snap-through acceleration and low bending stress is obtained. ANSYS software is used to calculate the spring constant and buckling results. A parallel curved beam is fabricated for the experiment using N-type silicon wafer and photoresist (AZP4620). By using this fabricated material, snap through requirement acceleration and maximum bending is reduced.

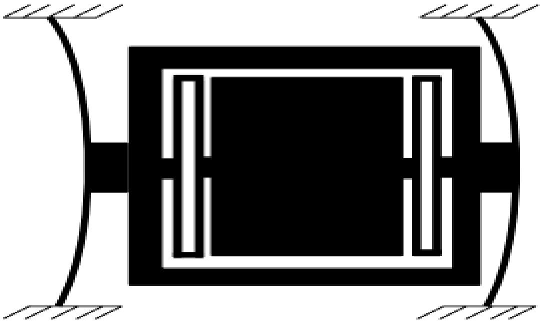
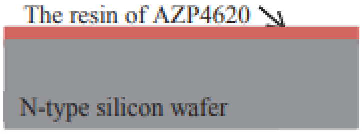


Fig. 9: Vibration energy harvester structure [4]



(a) Deposition of AZP4620

(b) Patterned the resin

Fig. 10: parallel curved beam fabrication process [4]

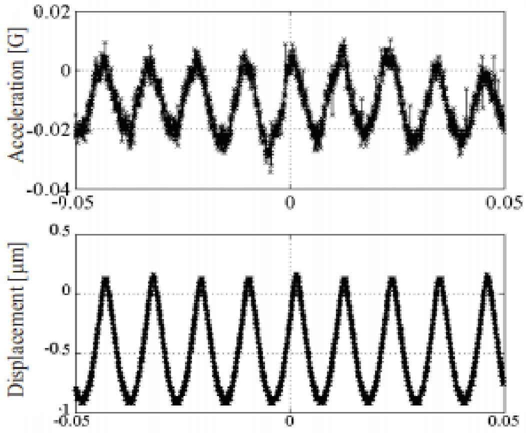


Fig. 11: output wave of parallel model at 90Hz [acceleration (G) vs time(s) & displacement (μm) vs time(s)] [4]

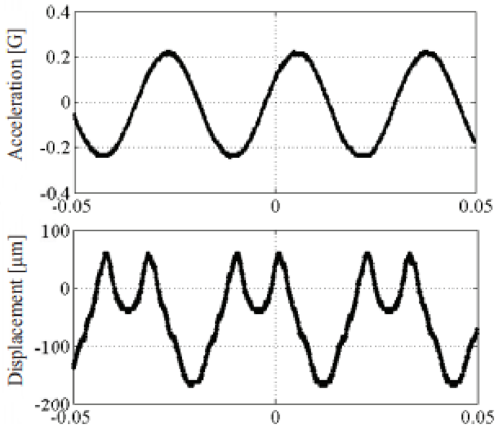


Fig. 12: output wave of parallel model at 30Hz [acceleration (G) vs time(s) & displacement (μm) vs time(s)] [4]

Yipeng Wu et al (2018) designed a simple piezoelectric spring incorporated with a binder clip. Harvester with pendulum spring allows energy to be converted into electrical energy using piezoelectric transducer. Pendulum is used in this research because of its common mechanical oscillators that can be excited in any direction. The resonant frequency of a pendulum only depends on the length of pendulum and gravitational acceleration. Multiple metal binder clips are arranged in series. The metal binders are attached with piezoelectric ceramic. The metal binders act as a spring. The equivalent stiffness is determined by the number of binders. The analysis is done by using Matlab Simulink and Dormand-Prince solver. The analysis done determined the horizontal acceleration excitation and the vertical acceleration excitation. Experiment is conducted by focusing on the horizontal excitations driven by human hands. Based on the research conducted, harvested power under high excited acceleration has the highest harvested average power, which is 13.29mW. It is found that maximum power higher than most of the previously proposed low-frequency vibration energy harvester can be obtained even though with variant in human clapping motion due to inconsistency.

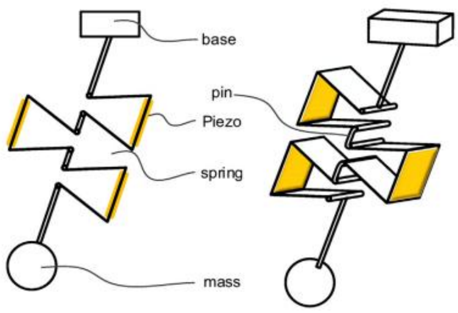


Fig. 13: Piezoelectric spring pendulum energy harvesting structure [5]

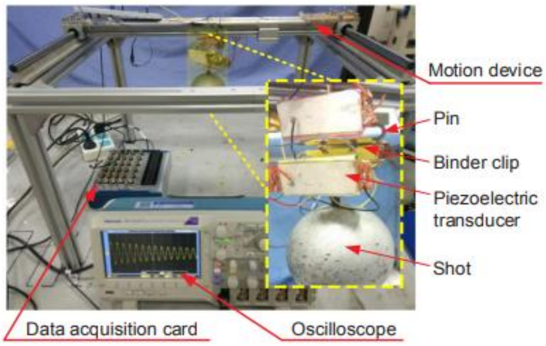


Fig. 14: Experimental setup [5]

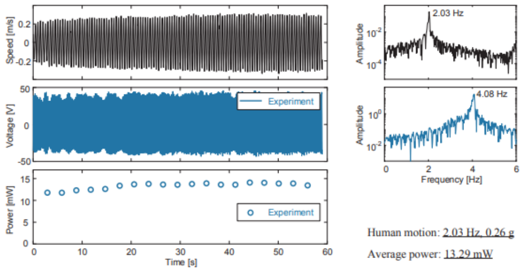
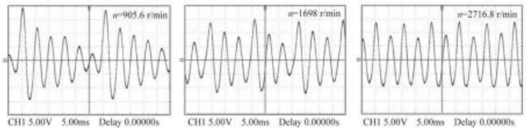


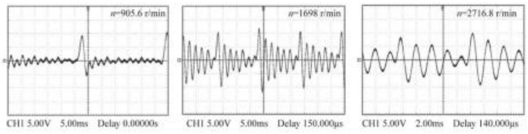
Fig. 15: Experimental waveforms and power spectral densities of human motion speed and piezoelectric output voltage and harvested power under the high excited acceleration [5]

Junwu Kan et al (2017) conducted a study on piezo-disk energy harvester excited by rotary magnets (PEHRM). This is done to study on energy harvesting by using rotating structures. For the simulation and analysis, several piezo-disks with different stiffness denoted by thickness/radius is used. As the stiffness increases, the effective bandwidth increases as well. For the experiment, several piezo-disks are fabricated and tested. A frequency changer is used to adjust rotary speed of the excited magnets. The research done concludes that all of the stiffness of the piezo-disks, exciting distance, and the number of exciting magnets has a high impact on energy generation performance on the PEHRM. By decreasing the number of exciting magnets, the effective bandwidth can be enhanced.

Fig. 16: Piezo-disk energy harvester excited by rotary magnets (PEHRM) [6]



(a) R_p=24mm, h_p=0.4mm



(b) R_p=24mm, h_p=0.6mm

Fig. 17: Voltage waveform at different rotary speeds [6]

Jeehyun Jung et al (2015) conducted a research studying on the nonlinear and energetic characteristics of an energy harvester system. The system is composed of a cantilever beam with two fully deposited piezoelectric layers and a tip magnet attached to the beam's free end. The system interacts with two external rotatable magnets fixed in free space. The two rotatable external magnets cause's external forces and torques to be produced thus affecting the tip magnet attached to the free end of the cantilever beam. The strength of magnets varies depending on the position of the tip magnet. The experiment is manipulated by using mono-stable,bi-stable and tri-stable energy harvesting systems. Based on the experiment conducted, it is concluded that the strong non-linear magnetic effect on the tip magnet has a hysteretic resonant behavior on all three type of energy harvesters.

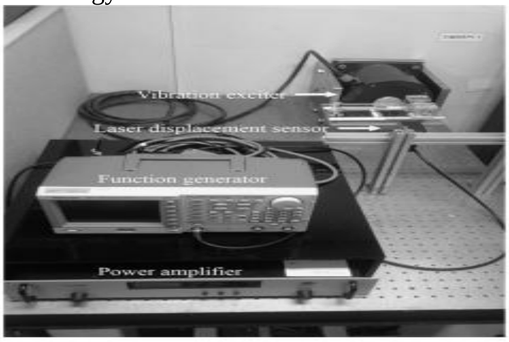


Fig. 18: Experimental setup of energy harvester [7]

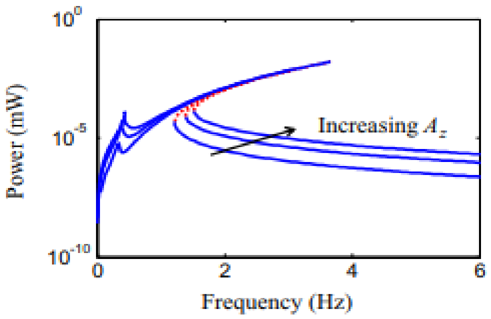


Fig. 19: Frequency response curves of mono-stable energy harvester system with generated power responses [7]

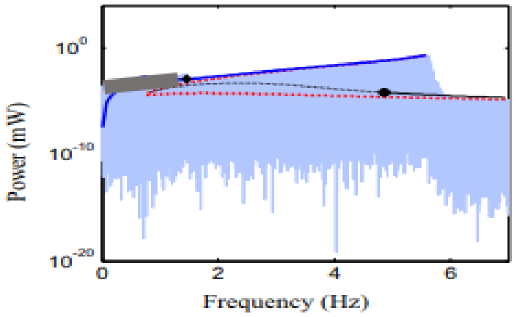


Fig. 20: Frequency response curves of bi-stable energy harvester system with generated power responses [7]

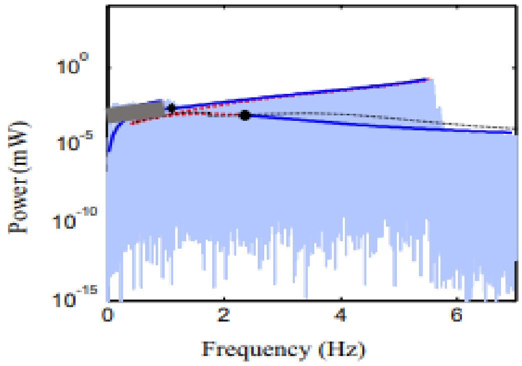


Fig. 21: Frequency response curves of tri-stable energy harvester system with generated power responses [7]

Mohammed Salim et al (2016) researches on the performance of an energy harvesting device and its capability to perform at different operating resonance frequencies. In process of designing the energy harvester, radial magnetic field is used as it is efficient in electromagnetic energy conversion. A brass reinforced PZT bimorph type is used as the cantilever for the PZT generator part. This is done to increase the amount of harvesting done. The usage of ring magnets are efficient for energy conversion because of its higher magnetic field density compared to axial magnets. Ring magnets produce more power compared to axial magnets. Tip mass and coil wire radius is manipulated in the experiment done. Based on the experiment, coil wire radius affects output voltage and power as thinner wire produces high voltage while thicker wire produces higher power.

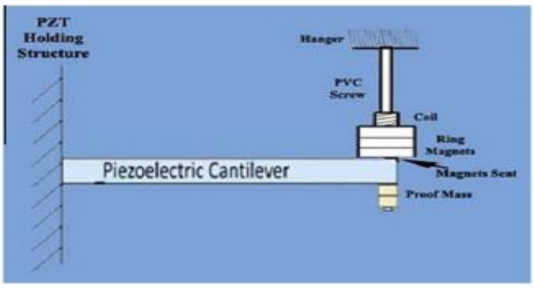


Fig. 22: Hybrid harvester schematic diagram [8]

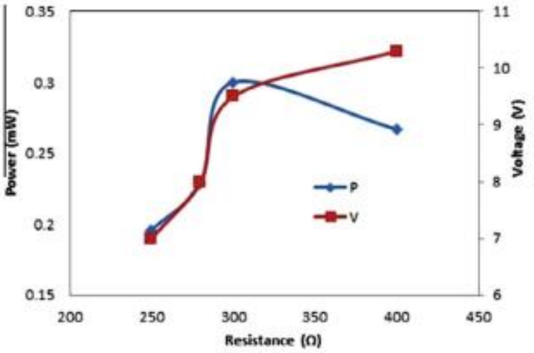


Fig. 23: Variations of power (PPZT) and voltage (VPZT) versus resistance for the PZT generator [8]

Xuexian Chen et al (2018) built a triboelectric-electromagnetic hybrid generator on a freestanding magnet (FMHG). Triboelectric nanogenerator (TENG) is developed to scavenge low-frequency mechanical energy in ambient environment. To acquire a higher energy conversion efficiency and broaden the operating bandwidth, TENG and electromagnetic generator (EMG) are hybridized. The basic idea of this experiment is, the fabricated magnet is placed at the middle of tested substrates. Different substrates are used. The movement of the device along the arbitrary plane will result in the electrons to move from leaving electrode to forward electrode causing current to be generated. The magnetic flux crossing the copper coil also increases and clockwise current is generated.

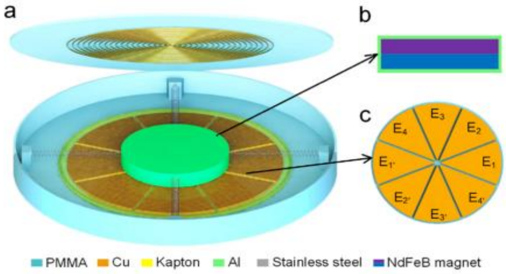


Fig. 24: Structural design of the hybrid generator [9]

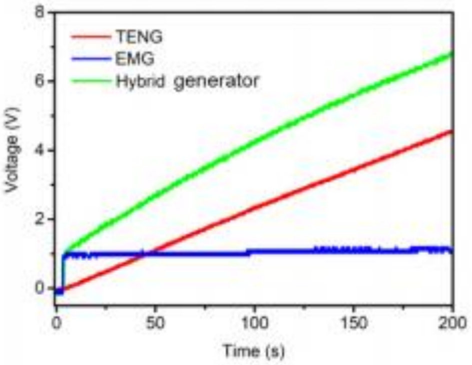


Fig. 25: Charging curves of a 20 µF capacitor using the hybrid generator. [9]

Wei Wang et al (2017) introduced a tunable magnetic-spring based electromagnetic energy harvester is introduced. The research team modeled the harvester using Ansoft Maxwell software. The software is used for electromagnetic field simulation software for the design and analysis of electric motors, actuators, sensors, transformers and other electromagnetic and electromechanical devices. The simulation is used to investigate the best way for magnetic stack to be chosen based on the generated voltage. The simulation is manipulated by letting opposite magnets face each other and then letting same pole to face each other. The distance between the two magnets are manipulated to investigate on the generated voltage. Based on the simulation, it is found that when magnets of the opposite polarity face each other, the generated voltage is unchanged. For the same polarity facing each other, the generated voltage increases when the distance increases. Based on Fig. 27, a maximum voltage 0.86 V is achieved at a frequency of 9.155 Hz under the acceleration level of 0.85 g and the bandwidth is 4.3 Hz from 5 to 9.3 Hz for forward frequency sweep.

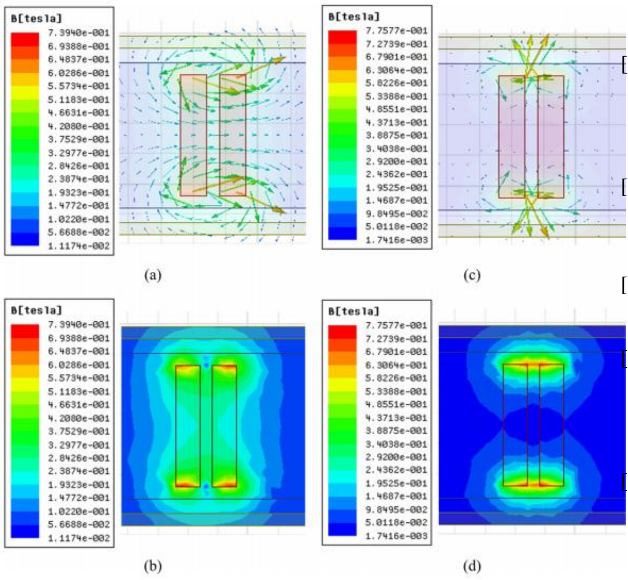


Fig. 26: Distribution of magnetic field and magnetic lines for two configurations: (a and b) opposite pole facing each other; (c and d) same pole facing each other [10]

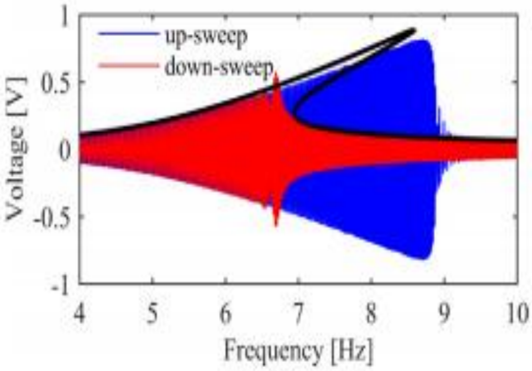


Fig. 27: Forward and reverse frequency sweep responses under 0.85g excitation [10]

III.CONCLUSIONS

Piezoelectric vibration energy harvesters have been used to generate electrical energy from the mechanical vibration emits from the surrounding. The are many methods have been used by the previous researchers in order to increase the maximum output voltage. In a simple one degree of freedom piezoelectric vibration energy harvester design, despite the high output voltage can be achived but the drawback is the decrease in the frequency bandwidth which the harvester can works on. This is directly influencing the amount of effective time needed to charge the capacitance in storing the useful energy. Therefore, more efforts needed to design a better piezoelectric vibration energy harvester which able to harvest energy from mechanical vibration in a wider frequency range.

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