Chapter 18

The use of Piezoelectric Energy Harvester in Speedbump with Passing Vehicle to Generate Clean Electricity

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ABSTRACT

With the world increasing consumption of energy demand, clean and renewable energy sources are getting more popular and piezoelectric energy harvesting is a subject undergoing intense study. Piezoelectric material contains crystals that can change mechanical vibrations into electric energy when mechanical stress is applied on it. However, a proper power generation on harvesting high output of voltage from piezoelectric material is not found yet. The idea of harvesting electrical energy from vehicles passing through speedbump at varies speeds is presented in this paper. Analysis on deflection and stress distribution on the speedbump by using ANSYS Workbench was analysed to convert the mechanical energy into electrical energy is possible. Explicit dynamics was used to study the behaviour of the wheel going over the speedbump and tile with Lead Zirconate Titanate (PZT) materials at six different velocities: 5km/h, 10km/h, 15km/h, 20km/h, 25km/h, and 30km/h. With better positioning of the piezoelectric energy harvester and power circuit, obtaining a high output voltage is possible. In this project, a highly stable output of 3V is achieved when the velocity of the car passing over the speedbump is above 15km/h.

Key Words: Piezoelectric, Mechanical Vibration, ANSYS Workbench, Explicit dynamics

1. INTRODUCTION

With decades of realization and environment concerns, alternative clean and renewable energies sources such as wind, hydroelectric, biomass, thermal, and atomic have been developed without polluting the world. Recently, Vibration energy has been discovered and it is a hot topic now. Vibration is found in everything, living or inanimate. Vibration's energy can be found in the impact of objects, tall buildings, machinery, vehicles, railways, and ocean waves (Kalyani et al., 2015). These waste vibration energies can be harvested to power low power electronics such as smart phones and LED lights. Thus, vibration energy is a good alternative of clean and renewable energy source. Vibration-to-electricity conversion is possible through three main transduction mechanisms:

electromagnetic, piezoelectric, and electrostatic transducers. Two of the most popular transducers are piezoelectric materials and electromagnetic transducers (Zhu, 2011).

In this project, the focus is on harvesting waste mechanical energy using piezoelectric energy harvesters. The piezoelectric effect was firstly discovered by the Curie brothers back in the year 1880 using crystals of tourmaline, quartz, topaz, cane sugar, and sodium potassium tartrate tetrahydrate which can generate electrical polarization when the material is under mechanical stress as shown in figure 1(Mould, 2007). Piezoelectric material contains crystals that can change mechanical vibrations into electric energy and this electric energy can be utilized later using a proper circuit storage system. The electrical energy has been produced when mechanical stress is applied. If electrical energy can be harvested from vehicles passing through speed bump, then the energy can be utilized to help power lights at parking lots or malls. Thus, this is a very effective way of energy generation since it will be economic and environment friendly. This project focus on harvesting waste energy from piezoelectric energy harvester placed under the speedbump during vehicles passing through with the help of ANSYS Workbench to determine the stress and deflection of speedbump at various speed. Lastly, a prototype is built and tested to determine the exact voltage generated when a vehicle passing through at varies speed.

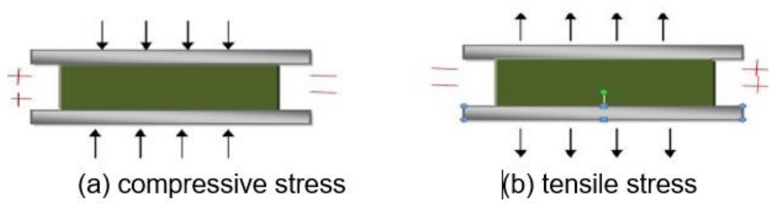


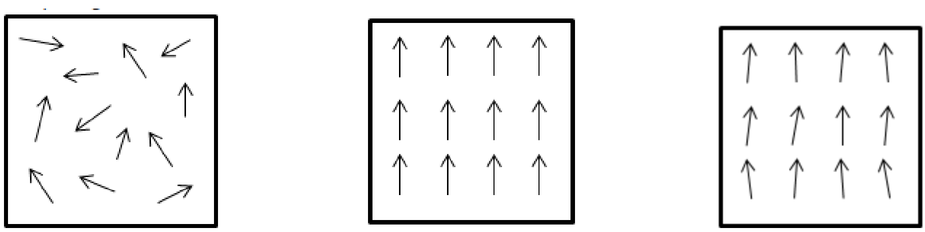
Figure 1: Two different types of stress on piezoelectric to generate piezo electricity

2. LITERATURE REVIEW

2.1 Piezoelectric Device

Piezo is derived from the Greek word ‘piezin’ which means to press and ‘piezo’ meaning to push. A piezoelectric material contains a crystalline structure with the ability to convert mechanical stress into electrical energy. This allows piezoelectric energy harvester to be used in any place such as building and bridges, aerospace systems, automobiles, and the human body. The advantages of piezoelectric energy harvester are excellent in their inherent transduction capacity, preservation of efficiency as the scale is reduced, high power density and compatibility withstand electronic technologies (Safaei et al., 2019).

Piezoelectric crystals consisted of microscopic electric dipoles which are randomly distributed within the material forming a net polarization. When this material is stressed, tiny polarization occurred and produces weak piezoelectric effect, hence generating electricity. To make the piezoelectric material much more piezoelectric sensitive, electric dipoles in the material must be aligned in the same direction to the applied forces. Alignment of the electric dipoles is possible by using the poling process, where a strong field is applied across the material at Curie temperature. The Curie temperature is a high temperature where the piezoelectric material loses its polarization and piezoelectric characteristics. During the poling process, electric dipoles in the material are forced to rotate in the direction of the electric. After polarization, the electric field is switched off and most dipoles do not return to their original orientation as shown in figure 2.



Unpoled During Poling After Poling

Figure 2: Electric dipoles of piezoelectric material. (Kok, 2010)

2.2 Piezoelectric Materials

There are a wide variety of piezoelectric materials which naturally exist in form of crystals such as quartz, Rochelle salt and tourmaline group minerals. However, the commonly used piezoelectric materials are polycrystalline ceramics (barium titanium, lead zirconate titanate PZT) and piezoelectric polymer (polyvinylidene fluoride PVDF, polyimide). Piezoelectric ceramic and lead zirconate titanate (PZT) was developed in the 20th century at the Tokyo Institute of Technology and it is currently the most used piezoelectric ceramic material due to its high coupling effects (Covaci & Gontean, 2020). Piezoelectric ceramic has found it uses in sensors and actuators due to their high direct coupling which enables it to operate without any bias voltages and their ability to output large voltage as high as 50V to 100V but currents are in the lower side of nanoamp to milliamp range (Safaei et al., 2019).

PZT is often manufactured in bulk, thin-film, thick-film, or polymer forms depends on its application and requirement from individual characteristics. PZT materials are classified as soft and hard PZT ceramics depends on their coercive field during field-induced-strain actuation and Curie temperature. A hard PZT has a larger coercive field ($higher\ than\ 1kV/mm$) and a higher Curie point ($T_c > 250℃$). Hard PZT has a high mechanical factor, high coercive field, and low dielectric constant which suitable for high-power applications like ultrasonic cleaning, welding, and high voltage generators. On the other side, a soft PZT has a lower coercive field ($around\ 0.1\ and\ 1kV/mm$) and moderate Curie point ($between\ 150℃ < T_c < 250℃$). Soft PZT has a lower mechanical Q-factor, higher electromechanical coupling coefficient, and higher dielectric constant properties. Hence, soft PZT is used to determine large response like sensitive receivers and fine movement control like jet printers (Horchidan et al., 2016).

3. METHODOLOGY

3.1 Finite element analysis using ANSYS Workbench Explicit Dynamics

The analysis setup of this project is consisting of a rubber speedbump, piezoelectric energy harvesters' tile and a wheel. The modelling of every part in this setup is drawn using Autodesk Inventor Professional 2021 and then exported to ANSYS Workbench 2021 R1 (Explicit Dynamic) to do Finite Element Analysis (FEA). This is to study the stress distribution and deformation on a rubber speedbump at varies speeds and optimization of the piezo tile for better power harvesting at different speeds. Boundary conditions such as "Standard Earth Gravity" (9.8 m/s^2) constrain is applied on the model at negative y-direction as shown in figure 3. "Fixed support" constrain is applied to the bottom and sidewall of the speedbump and concrete flooring. Then, the "External force" constrain of 3164N is applied on the wheel were based on 30% weight total of a Proton

Saga (Aboshady, 2019). The wheel has fixed external force to come from the ground moving towards the tire. Initially, velocity of 5km/h is applied on the wheel to move in the negative x-direction. The velocity been increased to 10km/h, 15km/h, 20km/h, 25km/h, and 30km/h. “Maximum Stress” is used to determine the localization of stress on the speedbump and PZT tile. This help on identifying high stresses area on speedbump and PZT tile. Meanwhile, “Total Deformation” is used to determine the maximum deflection on the speedbump and PZT tile when the wheel rollover. In addition, the use of maximum stress and maximum deformation features can easily identify a better arrangement of the PZT transducer due to the localization of stress and deflection.

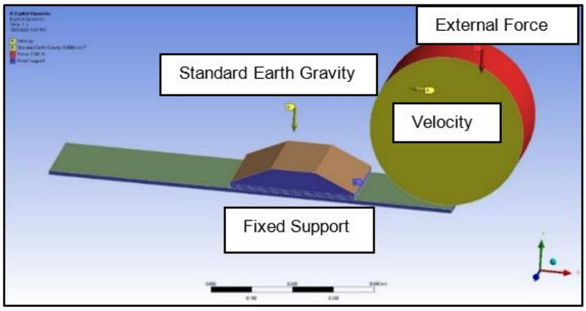


Figure 3: Boundary Conditions

3.2 Prototype Fabrication and Testing

A total of 56 piezoelectric transducers were connected in a series connection and were arranged in 5 rows as shown in figure 4. Then, each row of series connection is then connected to a full bridge rectifier to convert the AC into DC. A total of 5 full bridge rectifier is used in this prototype before connecting it all into a capacitor. Next, a total of 56 transparent rubber absorber pads are sticked onto each of the piezoelectric transducers to act as a cushion to absorb excessive stress and vibration that may crack the piezoelectric energy harvester. Lastly, the piezoelectric transducer is covered up with another plywood forming a piezo tile and the rubber speedbump is located on top of the plywood before bolting it down together. A digital multimeter is connected to the capacitor before a car will past over the prototype at varies speeds on actual road as shown in figure 5. The speeds of the car going over the prototype initially are at 5km/h, then it is increased to 10km/h, 15km/h, 20km/h, 25km/h, and 30km/h. In order to get an average result, each speed was repeated 10 times.

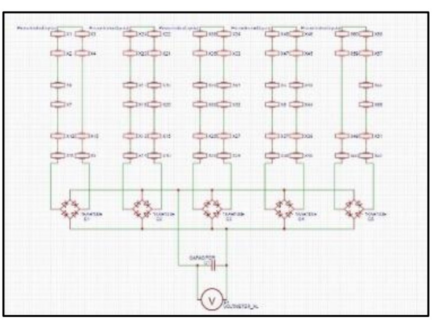


Figure 4: Schematic Diagram

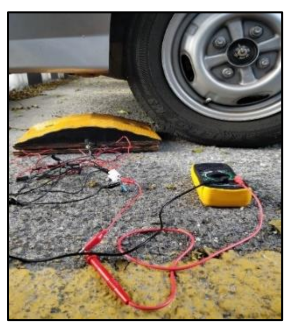


Figure 5: Testing Setup

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4. RESULT AND DISCUSSION

The simulation analysis has shown that the wheel has four contact points on the speedbump and PZT tile as shown in figure 6. It has been observed that the stress on the PZT tile is significantly higher than the speedbump and it is due to the stress area on the speedbump is bigger and the stress area on the PZT tile is much more concentrated as shown in figure 7. The contact between the wheel and the speedbump is minimal as the increased speed of the wheel going over speedbump at 10km/h, 15km/h, 20km/h, 25km/h, and 30km/h.

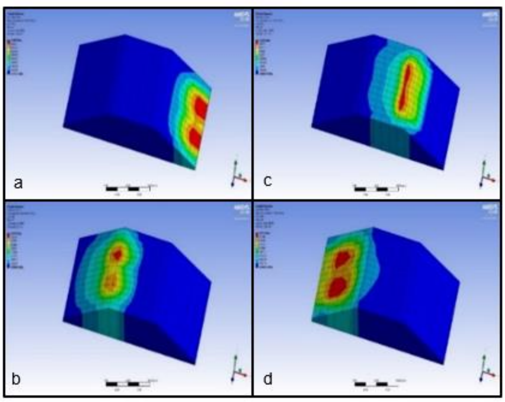

Figure 6: (a) initial (b) second (c) third (d) final stress on speedbump at 15km/h

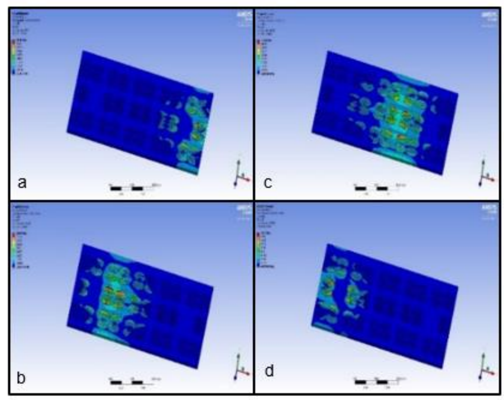

Figure 7: (a) initial (b) second (c) third (d) final stress on PZT Tile at 15km/h

Figure 8 shows the relationship of the maximum stress with different velocity. As the velocities of the wheel increase, the maximum stress on the speedbump increases linearly until a velocity of 15km/h. The decreases in maximum stress at a velocity of 20km/h, 25km/h and 30km/h is due to the wheel start to overshot at initial contact and take off right after having just minimum contact on the speedbump. Figure 9 shows the maximum deformation on the speedbump with different velocity. The maximum deformation of speedbump and PZT tile increases linearly until the velocity of 15km/h and then decreases right after at the velocity of 20km/h. As the increase in velocity of the wheel, causing minimal contact between the wheel and speedbump due to the overshot.

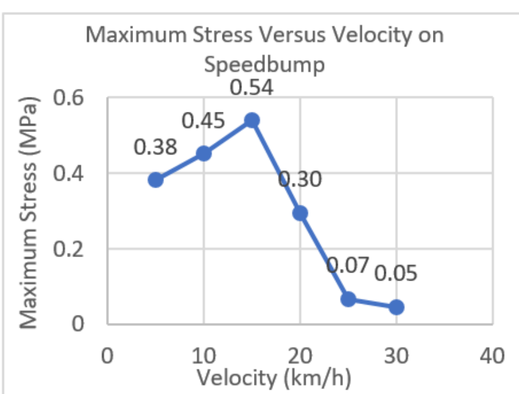

Figure 8: Graph of maximum stress versus velocity on speedbump

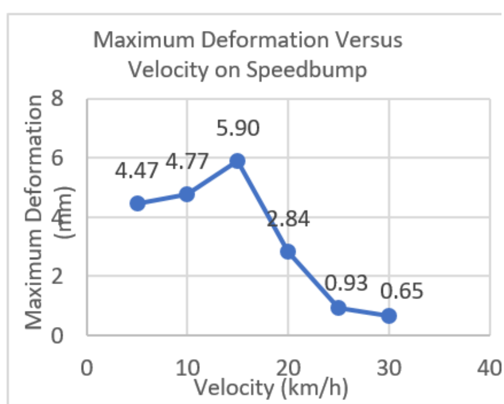

Figure 9: Graph of maximum deformation versus velocity on speedbump

The average generated voltage at different speeds over 10 cycles of wheel passed through the speedbump and PZT tile is shown in figure 10. The average voltage generated increases linearly as the velocity increase. The maximum voltage obtained is 3.611v at 15km/h. Then the average voltage was stabilized between speed 20km/h till 30km/h. This proof that the PZT tile may have reached maximum efficiency in harvesting energy.

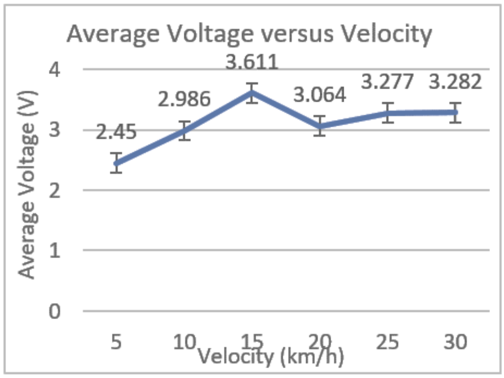

Figure 10: graph of mean voltage against Velocity

5. CONCLUSION

The study on deflection and stress distribution on speedbump at varies speeds was achieved with the help of ANSYS Workbench. From the result shown, it was indicated that the increasing velocity of a wheel going over a speedbump will increase the deformation and stress on the speedbump with a maximum stress of 0.54 MPa and maximum deformation of 5.898 mm at the velocity of 15km/h. In addition, ANSYS Workbench simulation also helped on the piezoelectric transducer arrangement due to the localization of stress and deformation. A total of 56 piezoelectric transducers were installed under the rubber speedbump to convert waste vibration energy into clean renewable energy. Stable output of 3.611V was achieved when a vehicle passed by the speedbump and PZT tile at speed of 15km/h. The high output of voltage is achieved with proper implantation of the circuit with multiple full-wave rectifiers to increase the power conversion efficiency from AC to DC. In order to improve the power harvesting of piezoelectric energy harvesters by implementing bi-layer piezoelectric. This can significantly double the amount of voltage output without increasing the cost of material by a lot.

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