Piezoelectric power generation in tires

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Abstract— the process of acquiring the energy surrounding a system and converting it into usable electrical energy is termed power harvesting. Piezoelectric materials have been used in various forms for energy harvesting using vibration, repetitive strikes and bending of structures. This paper review about the power generation using piezoelectric pulse generator and discuss the use of piezoelectric material with in a commercial vehicles pneumatic tire to harvest power that can be used to run onboard devices or to recharge the electric vehicle with the matlab/simulink simulation results . Power harvesting in two types of vehicle tires are explored in bike and car, with each having a different normal forces acting on the contact area of tire due to the vehicle weight acting on it.

Index Terms— Energy harvesting, piezoelectric power, piezoelectric pulse power, piezoelectric tire.

I. INTRODUCTION

The battery range of many Electrical Vehicles is limited, meaning that such methods of transportation can only be used for short trips. However Extended range electric vehicles or plug-in hybrids, Manufacturer include an internal combustion engine that uses conventional fuels to recharge batteries in motion and hence extend their range. The need remains for the cleaner power generation technique that allows maximum range extension with minimum environmental consequences.

Piezoelectric materials generate electrical energy when subjected to mechanical strain. Mechanical stresses applied to piezoelectric materials dissort internal dipole movements and generate electrical potentials (voltage) in direct proportion to the applied forces. These materials have long been used as sensors and actuators. One of the early practical applications of piezoelectric material was the development of first sonar Sound Navigation and Ranging) in 1971. The same properties that make these materials useful for sensor can be utilized to generate electricity. Such materials are capable of converting the mechanical energy of compression in to electrical energy. Power generation devices based on such devices have surfaced in recent years in context of vibration-energy harvesting., but developing a piezoelectric generator is challenging because of their poor source characters (high voltage, low current, high impedance). Their output has only been sufficient to power sensors and other small, low-energy-consumption gadgets. However researchers like chok kea wboonchuay [1], pearson[3] studied and demonstrated the high power generation using piezoelectric stacks.

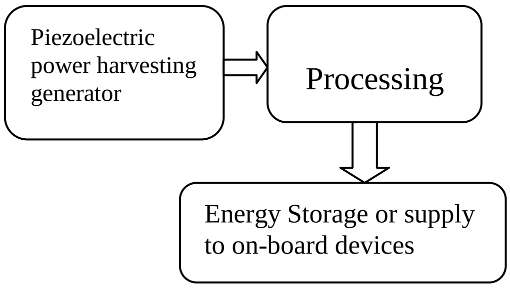


Fig 1: system model of piezoelectric energy harvester

The basic block diagram of the piezoelectric power harvester model is shown in fig 1. The piezoelectric Energy harvester block converts the mechanical energy surrounding the system into electrical Energy. The output of the piezoelectric harvester is an alternating voltage hence it is further rectified and dc to dc converter used to improve the current level since the piezoelectric device having poor source characteristics. The processed power utilized to supply onboard devices or energy storage.

II. PREVIOUS WORKS

Several recent studies have investigated piezoelectric power generation. One study used lead zirconate titanate (PZT) wafers in shoes to convert mechanical walking energy into usable electrical energy. This system's proposed use was to provide 1.3 mW at 3v when walking

[5]. Other projects propose the use of piezoelectetric generators to extract electrical energy from mechanical vibrations in machines to power MEMs devices. This work extracted a very small amount of power (<5μW) from vibration and no attempt made to store the energy [5].

Yet another development of piezoelectric generator was performed by Engel as the source of landmine detection in 1996 [5]. One particular investigation shows the peak power output of the experimental generator ranging from 7 to 28 kW. The investigation also shows s that maximum peak power scales with increasing piezoelectric volume. This work uses piezoelectric materials to convert kinetic energy into a spark to detonate an explosive projectile on impact.

Energy harvesting with in tire has been of greatest interest in the recent past for the purpose of powering sensors such as Tire Pressure Monitoring (TPMS) sensor, Vehicle Speed Sensor (VSS), Strain monitoring sensor (SMS) etc. Some interesting ideas have emerged utilizing piezoelectric elements to harvest energy through vibration, impact and bending [8]

III. THEORY OF PIEZOELECTRIC POWER GENERATOR:

Piezoelectricity is a phenomenon that certain crystals can induce strains when they are subjected to electric fields and can generate electrical charges when they are subjected to mechanical deformation. A piezoelectric crystal exhibits the piezoelectric effect because its elementary cells do not have center of symmetry. Compression or stress applied to the piezoelectric crystal would change the distance between negative and positive charges of the crystal, resulting in the development of electric field on the surface of the crystal.

Fig 2 illustrates the operation mode of the piezoelectric material. In generator mode piezoelectric material develops a voltage or electric field when subjected to a compression and expansion. In actuator mode when the piezoelectric material is subjected to an applied voltage, the piezoelectric material expanded if the applied voltage is opposed to the poling direction and is compressed if the applied voltage is in the same direction as poling direction (polling: initially, the piezoelectric ceramics are non piezoelectric due to the random arrangement of each crystal in the ceramics, resulting the cancellation of piezoelectric effect. To create a piezoelectric effect in ceramics, a strong electric field is applied to the material, which is called polling)

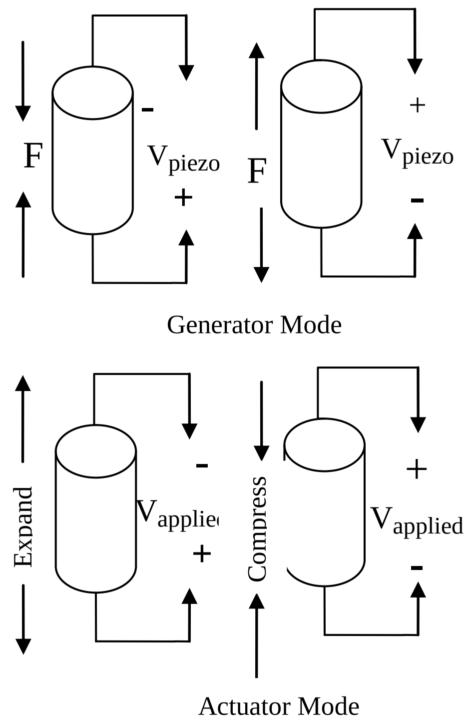


Fig 2: operation modes of piezoelectric device

The efficiency with which the material converts mechanical energy is given by coupling constant or electro mechanical coefficient indicated by 'Kij'. Since piezoelectric material is anisotropic, each constant of the piezoelectric material has two subscript notations. 'i' identifies the direction of action while 'j' identifies the direction of response. Electro Mechanical Coefficient K describes the efficiency that the piezoelectric material converts electrical energy to mechanical energy and vice versa. As a sensor' K' is defined as the square of the ratio of stored converted electrical energy to the input mechanical energy, conversely, as a actuator 'K' is the square of the ratio of the stored mechanical Energy to input electrical Energy.

$$K = \sqrt{\frac{Mechanicle\ Energy\ Stored}{Electrical\ \ Energy\ Applied}} \qquad (1)$$

Or

$$K = \sqrt{\frac{Electrical\ \ Energy\ Stored}{Mechanicle\ Energy\ Applied}}$$

IV. MECHANICAL MODEL

The main purpose of modeling the mechanical system is to understand the physical behavior of the piezoelectric pulse generator when the mechanical stress is applied.

The displacement of piezoelectric material under the applied stress can be obtained in this step. With the displacement the mechanical energy and the stack voltage of the generator calculated.

The force applied externally is parallel with the poled direction of the piezoelectric material. The applied force is assumed to be instantly and uniformly distributed throughout the device. So simple spring-mass system is used.

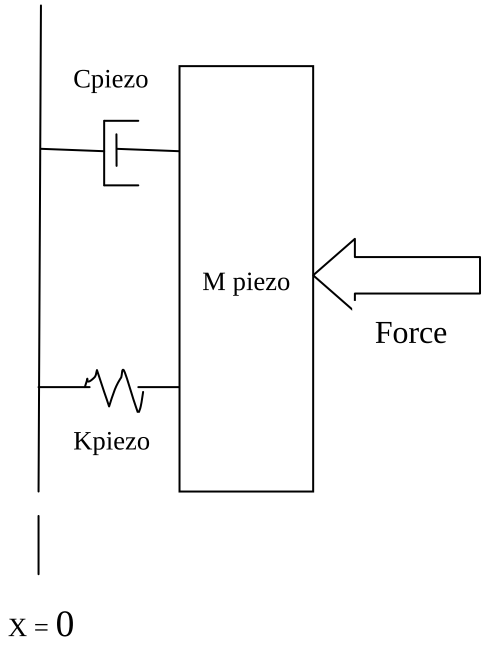


Fig 3: mechanical modeling of piezoelectric device

The mechanical system in the above fig 3 is described by second order Equation given by

$$F = M_{piezo}\ddot{x}_{piezo} + C_{piezo}\dot{x}_{piezo} + K_{piezo}x_{piezo} \quad (2)$$

In this equation, is the M_{piezo} mass of the piezoelectric material, C_{piezo} is the internal damping of the piezoelectric material and K_{piezo} is the spring constant of piezoelectric material.

For any given compression, the mechanical energy stored in the system is calculated as external force F, times the average compression distance given by

$$W_{mech} = Fx_{piezo} \quad (3)$$

By relating the young's modulus to the spring constant of the system, it is possible to rewrite the stored mechanical energy of the system in terms of piezoelectric constants [1].

$$W_{mech} = \frac{1}{2}\frac{F^2 h_{piezo}}{YA} \quad (4)$$

In electrical domain, the energy stored in material can be calculated as,

$$W_{elec} = \frac{1}{2}\frac{q^2}{C_{stack}} \quad (5)$$

The coupling constant which describes the relationship between W_{mech} and W_{elec} is given as

$$K_{33} = \sqrt{\frac{W_{elec}}{W_{mech}}} \quad (6)$$

The generated voltage is given by

$$V_{stack} = K_{33} = \sqrt{\frac{2W_{mech}}{C_{stack}}} \quad (7)$$

V. FORCE

The most efficient energy conversion comes from compressing PZT; Even so, the amount of effective power that could be transferred in this way is minimal, since compression follows the formula

$$\Delta H = \frac{FH}{AY} \quad (8)$$

Where F is the force, H is the unloaded height, A is the area over which the force applied, and Y is the elastic modulus. The elastic modulus of piezoelectric material is in order of 10^{10} Newton's/meter^2. Thus it would be take an incredible force to compress the material a small amount. In this paper I consider the forces available at the wheel-ground contact normal forces of moving vehicles. The tire forces are generated inside the contact patch, in other words between the tire and the ground. The vertical forces that act on each of four wheels are given by [4]

$$F_{zfl,fr} = \frac{1}{2}m_v\left(\frac{l_r}{l}g - \frac{h}{l}a_x\right) \pm \left(\frac{l_r}{l}g - \frac{h}{l}a_x\right)\frac{h}{e_f g}a_y \quad (9)$$

$$F_{Zrl,rr} = \frac{1}{2}m_v\left(\frac{l_f}{l}g - \frac{h}{l}a_x\right) \pm \left(\frac{l_f}{l}g - \frac{h}{l}a_x\right)\frac{h}{e_r g}a_y \quad (10)$$

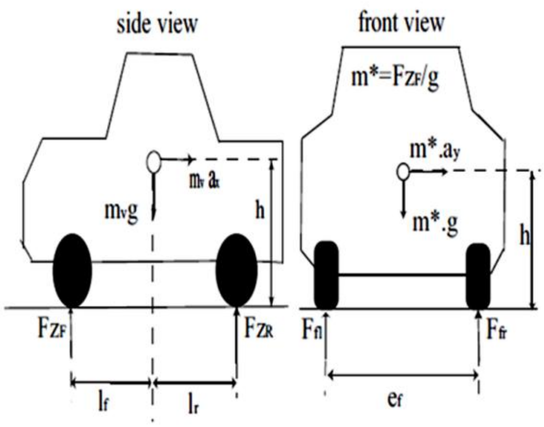


Fig 4: Wheel Ground Contact forces

VI. SIMULINK MODELING OF PIEZOELECTRIC POWER GENERATOR

A. Mechanical Energy:

Algorithm:

Step 1: open matlab/ simulink software [9]

Step 2: in command window type the simulink then the simulink library will open then got o file and choose new model.

Step 3: construct the model for the Mechanical energy equation using the simulink blocks in the library by drag and drop.

Step 4: assume force as constant. Ideally it is a pulse. But for simplification of the model we assume it as the constant. Value of the force is calculated from the force model.

Step 5: by changing the force from 0 to 10000 keeping constant values for diameter and thickness plot the graph for Force Vs Wmech.

Step 6: by changing the thickness and diameter values and keeping the force at constant values at 800 N and 5000 N plot the graphs for the both Thickness VS mechanical Energy and Diameter VS mechanical energy respectively.

Model:

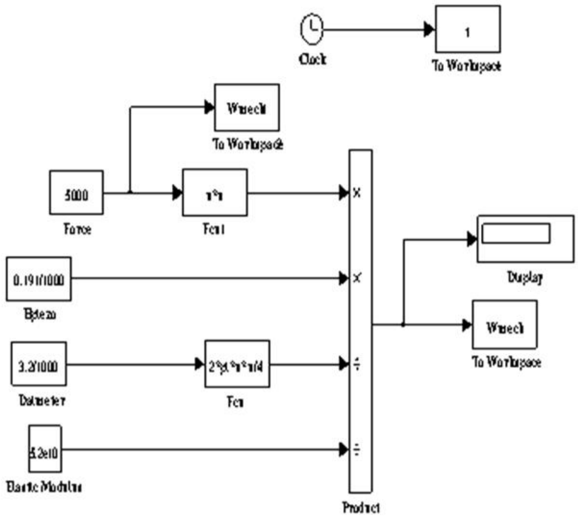


Fig 5: simulink model for mechanical energy

The above fig 5 shows the simulink model to calculate mechanical energy stored in the piezoelectric material for the applied force. The inputs to the model are the force and physical properties of piezoelectric disc.

The mechanical energy stored in the piezoelectric disc is increase linearly with the applied force and thickness of the piezoelectric material.

B. Stack Voltage

Algorithm:

Step 1: Repeat the step1 and step 2 in the mechanical energy model algorithm

Step 2: construct the model for the Vstack equation using the simulink blocks in the simulink library.

Step 3: by changing the force, thickness and diameter one at a time and keeping the other two values at a constant value plot the graphs for Force VS Vstack, Thickness VS Vstack and Diameter VS Vstack Respectively.

Model:

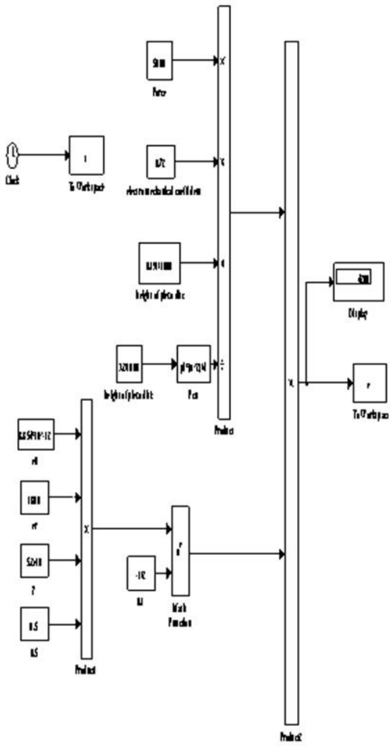
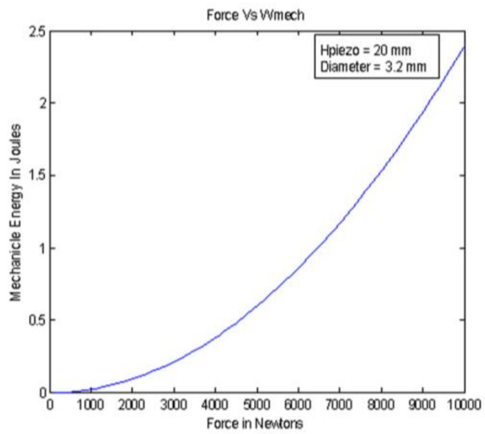


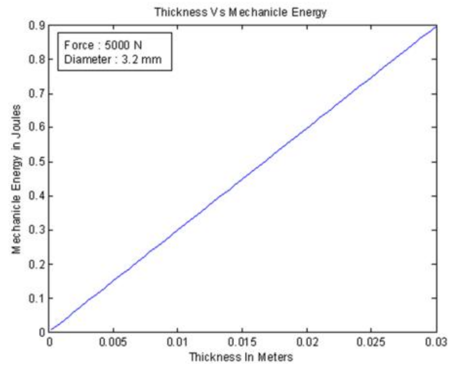
Fig 6: simulink model for stack voltage

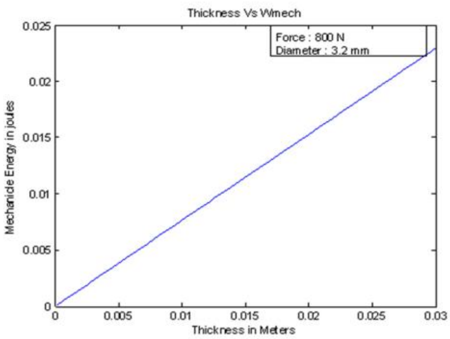
The fig shows the simulink model to calculate the stack output voltage for the applied forcce and given parameters of the piezoelectric disc.

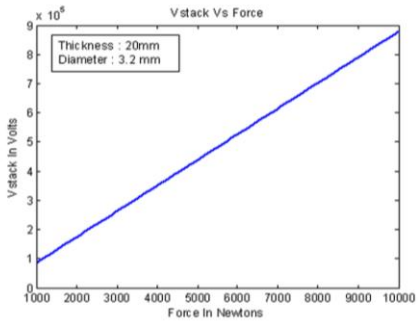
The output voltage is increases linearly with the input force, thicknessand the capacitanc of the piezoelectric device. and decreases with the increase of the area of the piezoelectric disc i.e. diameter of the disc.

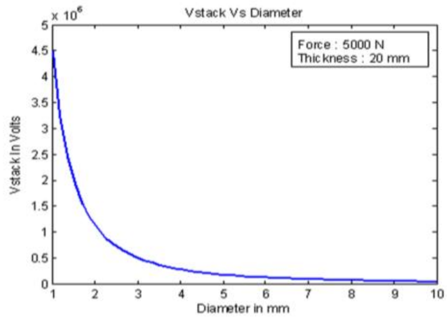
VII. PLOTS/RESULTS

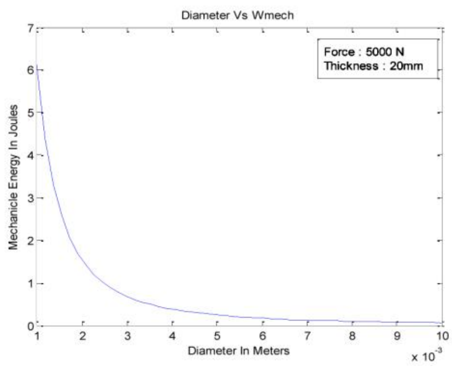


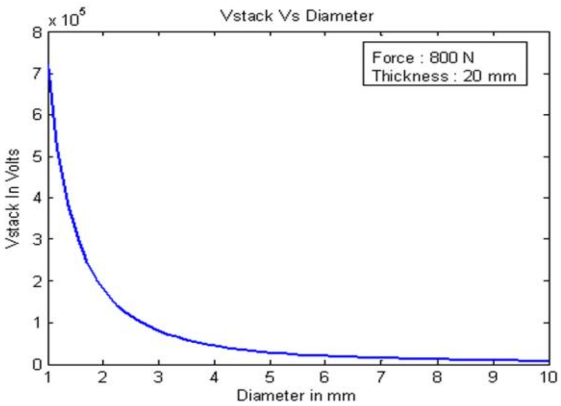


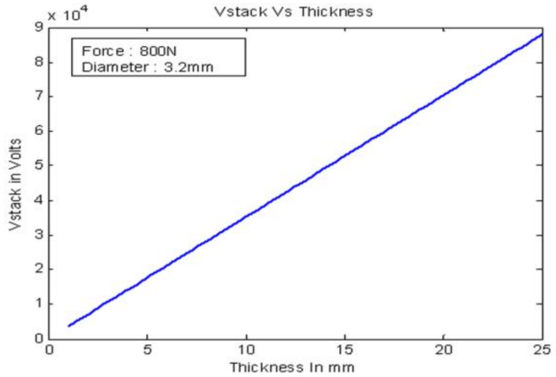


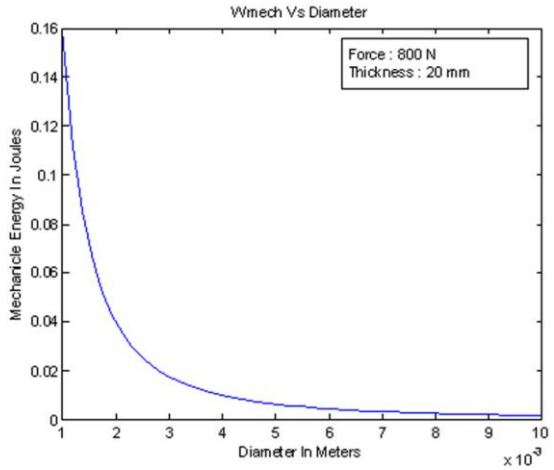


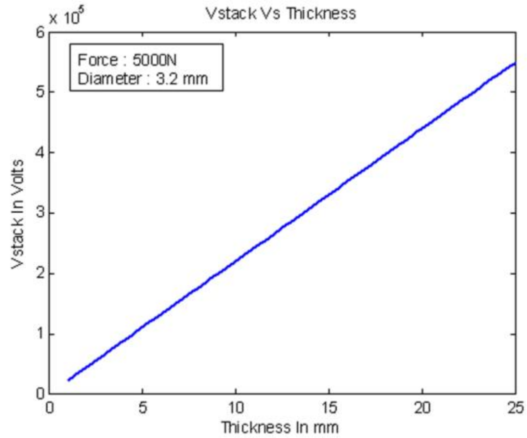












VIII. CONCLUSION AND RESULT ANALYSIS

The piezoelectric device acts as an efficient energy conversion devices. Energy Generated by a piezoelectric harvester is a renewable source of energy, thus it would be cater the needs of the future generation where the energy crisis are sure to occur. The normal forces available on the tire contact patch of the vehicles are efficient enough to generate the energy to power the on board electronics and able to recharge the batteries of Electric Vehicles if we design an efficient system.

From the plots it is shown that the mechanical energy and stack voltage both increase with applied force and thickness and drastically decrease with the increment in the Diameter of the piezoelectric device. The applied force normally constant since it depends on the weight of the vehicle. So by carefully choosing the piezoelectric material diameter and thickness will allow supplying enough energy to supply onboard devices and even charge the batteries.

IX. ACKNOWLEDGMENT

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X. REFERENCES

[1] Investigation and optimization of piezoelectric pulse generator PhD dissertation by chok kea wboonchuay.

[2] An investigation and characterization of a high energy piezoelectric pulse generator thesis by Pinkston.

[3] Modeling and development of Piezoceramic energy harvester for munitions applications thesis by pearson.

[4] An estimation process for vehicle wheel-ground contact normal forces by Moustapha Doumiati, alessandro Victorino et al.

[5] On low- frequency Electric power generation with PZT Ceramics by Stephen R. Platt

[6] Human-powered Wearable Computing by T.Starner.

[7] Piezoelectric harvester- model and proposed new Applications by Kshitiz Upadhyay.

[8] Piezoelectric power generation in automotive tires by noaman Makki and remon Pop-lliev.

[9] Matlab version 2012b, The Math Works Inc., 3 Apple Hill Drive, Natick, MA 01760-2098

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