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Highly Efficient Piezoelectric Generation in Tyres

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***Abstract*—**

This paper presents highly efficient Piezoelectric Generation in tyres with future scope and applications of its generation. This system is very much helpful for the battery operated vehicles as the concept involves the generation of electricity with the help of piezo material which are arranged in elastomeric belt of high strength placed in tire inner walls above the tire-to-road contact patch adjacent to the shoulder of tire. Piezoelectric material like Lead Zirconate Titanate (PZT) is employed for this purpose which is placed in inner walls of tires and experience sudden vibrations, bending of structures, when the tire rotates, which in turn according to the property of piezoelectric material generates electricity. This generation largely depends upon revolution of tire, amount of weight acting and proper placement of piezoelectric material.

***Keywords*—**Piezoelectric; Lead Zirconate Titanate (PZT); Tire; Elastomeric belt

Introduction

From the past few years, harvesting energy from the tires is of great interest and we have already succeed in harvesting energy through magnetic flux induction but generation of energy from piezoelectric material is less implemented or practiced in automotive vehicle. Piezoelectric generation provides a method of powering many electronic devices which are used for tire monitoring system which are selected from the group consisting of a pressure sensor, a temperature sensor, an acceleration profile sensor and a tire wear monitor. The main purpose of having this project is to increase the efficiency of battery operated vehicle by generating more power by installing this concept in every wheel of vehicle. Piezoelectric elements are used to harvest energy through vibration and bending of such elements.The scope of the project is to focus on the fields of ecology and terrestrial transportation. The purpose of the project is to reduce the use of non-renewable fuels, as well as to reduce pollution mediums (the ecological impact) which in these days are resulting into catastrophically consequences and fossil fuels like diesel and petrol are on the verge of its

Theory of Piezoelectric Generation

Piezoelectric is a concept which is responsible for the generation of electricity by converting mechanical energy into electrical energy. The level of the electric energy is variable according to the variations of the mechanical energy. 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. The force is only applied parallel with the poled direction of piezoelectric material. This energy is then utilized for various purposes in tire monitoring system and increasing the efficiency of battery operated vehicle.

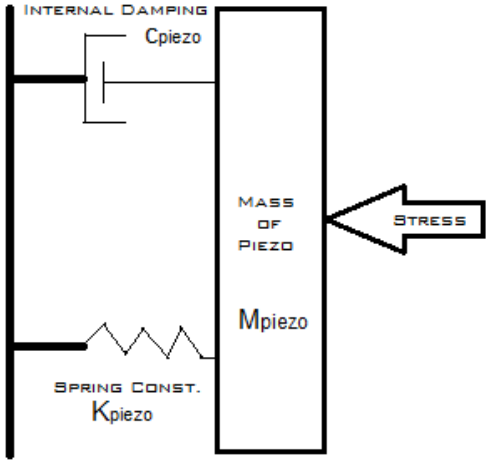

Fig.1: Mechanical Model of Piezoelectric Material

According to the second order equation:

$$F = M\text{piezo}\ddot{X}\text{piezo} + C\text{piezo}\dot{X}\text{piezo} + K\text{piezo}X\text{piezo}$$

M piezo is the mass of the piezoelectric material, Cpiezo is the internal damping of the
Piezoelectric material and K piezo is the spring constant of piezoelectric material.

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When stress is applied on piezo material the mechanical energy is calculated as external force applied.

$$W_{\text{mechanical}} = \frac{1}{2}\frac{F^2 h_{\text{piezo}}}{YA}$$

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

$$W_{\text{electrical}} = \frac{1}{2}\frac{q^2}{C_{\text{stack}}}$$

Generated voltage is given by,

$$V_{\text{stack}} = \frac{\sqrt{2W_{\text{mech}}}}{\sqrt{C_{\text{stack}}}}$$

Deformation of the Tire and Installation of piezoelectric material in tires

Energy for in-tire use is generated from the load induced reciprocating deflection of the tire inner walls above the tire-to-road contact patch adjacent to the shoulder of the tire. The piezoelectric material are mounted with a trigger and series of these material are arranged in elastomer diaphragm or belt under the inner wall of tire and each time when the tire rotates and under the load of vehicle, tire gets flatten and form a contact patch with a road and exert force on piezoelectric material which causes the effective bending in piezo element and converts mechanical energy into electrical energy and thereby can be stored in storage unit. As the vehicle moves, new area of the tire continually deforms and relaxes in a cyclic pattern whose frequency is dependent upon the vehicle velocity.

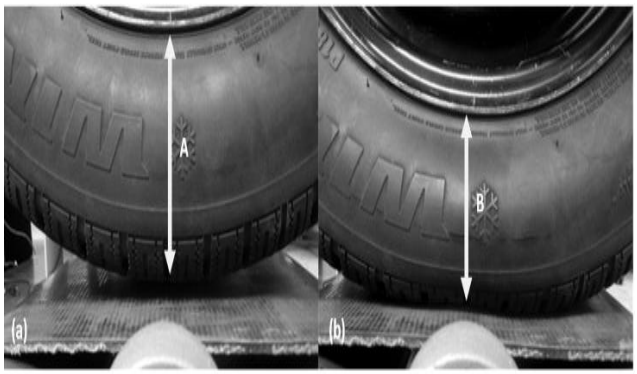

Fig. 1: (a) Tire under no load (b) deformation of the sidewall and creation of a *Contact Patch* due to vehicle weight (B < A).

Piezoelectric material are mounted on highly tensile strength of elastomer belt which is placed under the inside wall of tire circumferentially. In this research paper the experiment is conducted by using Lead Zirconate Titanate (PZT) as piezo material and all necessary calculation is done to check for the amount of current generation. The figure below shows the piezoceramic element on the inside of curvature of tire.

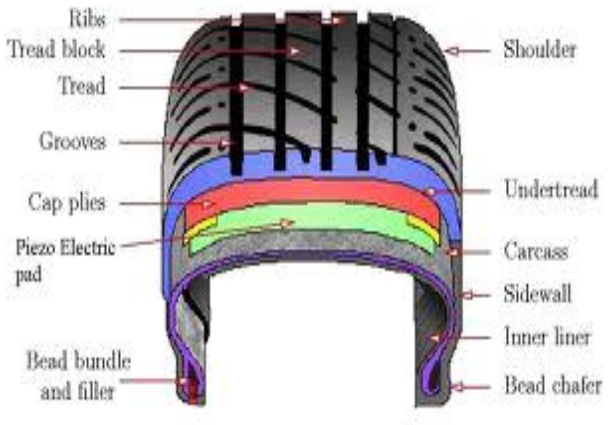

Fig-2 Piezoelectric tire installed with pad

Method of Generating Energy using Lead Zirconate Titanate (PZT)

By bonding Lead Zirconate Titanate (PZT) to the tire's Inner Liner. Piezoelectric material/elements are mounted on highly tensile strength of elastomer belt which is placed under the inside wall of tire circumferentially. When the tire rotates as the vehicle accelerate, the piezoelectric element/material extends and elongate when comes in contact with surface experienced force from the ground and charge gets generate and resultant voltage differential is also developed. This generated and released charge when enter into the circuit produce current in opposite direction. The available current is then stored in rechargeable batteries or capacitors or ultra-capacitors which thereafter can be used for various purposes. The amount of current produced largely depends upon the weight of the vehicle, speed of the vehicle (revolution per minute of the wheel), storing capacity of capacitors or rechargeable batteries, type of the arrangement use, selection of the piezoelectric material.

By using the weight of the combine product (vehicle+cargo) against the piezoelectric generator to produce energy, we will reduce fuel consumption and increase hybrid vehicles performance.

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According to the practical research work carried out by Noaman Makki and Remon Pop-Iliev, Faculty of Engineering and Applied Science, University of Ontario Institute of Technology. They designed a working energy harvestor by using Lead Zirconate Titanate (PZT) and took 150cc R15 vehicle tire which has 3.15 mm of end-to-end deformation for a 40 mm element which is beyond the capacity of many PZT benders which are readily available in the market. However, the PZT elements used in their paper can withstand up to 9 mm deflection without physical damage or a permanent shape change; almost thrice as much as the requirement. These elements are only bendable to such a high degree in one direction and can undergo much less deformation in the other direction. Bonding of these elements is achieved through the use of very flexible high temperature adhesive which allows the element to deform with the tire while having minimal effects on the deformation pattern of the tire.

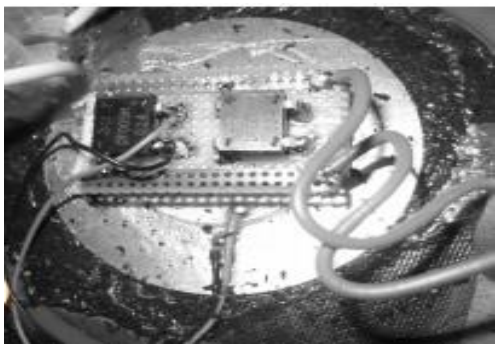

Fig-3 Piezoelectric tire installed with PZT (Lead Zirconate Titanate)

The rectifier attached on top of the element can also be seen with wires extending out to the rim. These elements generate a voltage peak with each revolution with maximum voltage rising as high as 45.5V. In order to calculate the maximum power generated by each deformation various resistive loads were connected in parallel to the PZT element and the output voltage was measured. A maximum of 4.6 mW of power can be extracted from the element bonded to the tire at a load resistance of 46 kΩ and a rotational wheel speed of 80 revolutions per minute (RPM), roughly equal to 9 km/h.

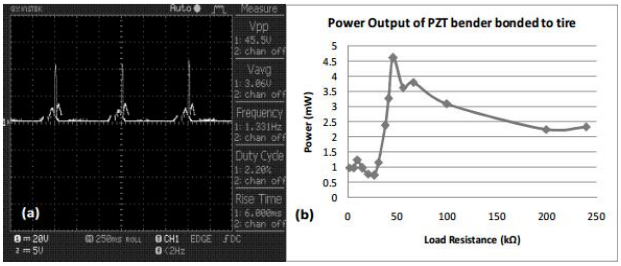

Fig-4 Voltage peaks produced by PZT upon each deformation, and (b) Power delivered to various resistive loads

General Circuit Diagram

The General Circuit Diagram depicts how the whole system works when piezoelectric tires get installed in a four wheel vehicles and also shows diverse circuits of a vehicle (power electric circuit to move the electric motors, batteries recharge's electric circuit, command and controller circuits, mechanic power circuit, and alternating recharge circuit).The generated electric current is transferred to the vehicle's battery through an appropriate circuit, and it is stored to be used by the vehicle.

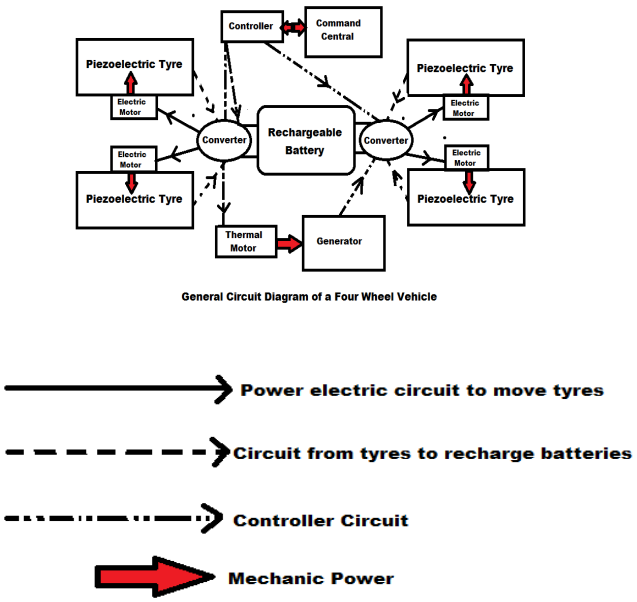

Fig-5 General Circuit diagram with line depiction

Result

In order to better quantify the power production capability of PZT material it should be better examined based upon its generation on the per unit area basis. PZT material/transducer with dimension of 25 mm disc and area of approx. 485 mm^2 are capable of generating 4.6 mW of power and $9.4*10^{-3}$ Mw/mm^2 (Power/Area). The energy generated by PZT element are quite very large as compared to other piezoelectric material or element which are readily available. A very important factor involved with the use of piezoelectric materials for energy harvesting is that of cost; high cost of harvester can prove to be a major hurdle in their wide scale usage and replacement of permanent power storage medium such as batteries. The PZT elements are relative cheap at Indian Rupees 110 per piece for a 491 mm^2 ceramic area.

Conclusion

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. Based on the experimental results, PZT elements directly bonded to the tire have the higher power output per unit area as well as cost but offer lower flexibility. A novel method using a plastic ribbon with PVDF elements was also presented as an alternative with attractive advantages over direct bonding of piezoelectric elements to the tire. In any case, piezoelectric energy harvesting can be effectively used as a substitute for limited capacity batteries in wheel embedded sensors to elongate their useful life.

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