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Design of a Piezoelectric Wheel for Power Generation in Automobiles

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***Abstract* - This project aims to seek the current status of piezoelectric energy harvesting technology in running vehicles. The goal is to assess the piezoelectric value to be considered as a future reliable energy source for vehicles which rely on results from prototype demonstrations. Piezoelectric materials can transfer mechanical energy into electrical energy. This kind of energy can be stored and used for other devices. In this case, piezoelectric materials have the potential to provide reliable and cost effective replacement of energy sources. Thus, it can ultimately have potential to replace the battery and reduce user costs. This project evaluates the future potential of piezoelectric energy harvesting technology in vehicles. The use of piezoelectric materials in pneumatic tires enables capturing waste energy of vehicles because of deformations in the tire and weight of the vehicle as well.**

Keywords - Piezoelectric wheel, alternative energy, quartz , tire, economical

INTRODUCTION

Concerns for depletion of fossil fuels and their adverse effects on the surrounding environment are increasing. Therefore, alternative non- conventional energy sources are gaining popularity in society. Solar cells, wind turbines, hydroelectric power generation, biogas and biodiesel plants have been implemented successfully. Nowadays, new technologies have been found to provide sustainable energy to harness waste energies with self-power energy harvesters to supply power needs of vehicles. This type of need is better to offer clean, more sustainable forms of electrical power to decrease the costs, to preserve reliable and fruitful connections with society members and to guarantee a healthier environment for the next generation.

As a new technology, piezoelectric materials and their effect can have a major role in solving the mentioned problems. Vibration harvested from human and vehicle motion, machines, and any surface under vibration is one of the easiest ways to harvest energy by piezoelectric materials. They convert mechanical energy into electrical energy. One of the natural piezoelectric materials already in use is quartz. There are some artificial piezoelectric materials like BaTiO3, lead zirconium titanate etc. On the other hand, since the invention of the vehicle, passenger's car fuel consumption has risen consistently. According to Canadian greenhouse gas (GHG) emissions by economic sector, in 2015, the transportation sector was the second largest source of GHG emission which has local, regional or global effect on environmental [1] receptors (people, materials, agriculture, ecosystems, climate, etc.) (Fig. 1.1).

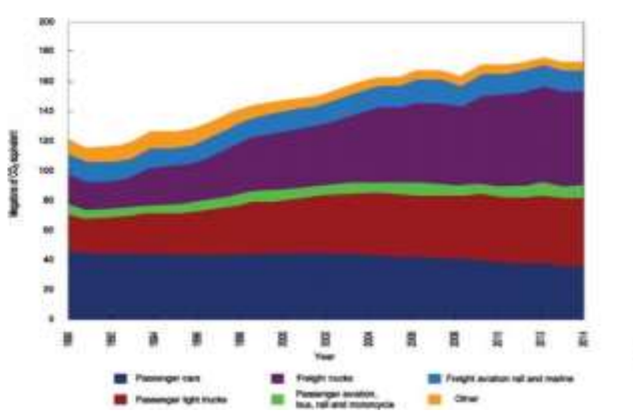

Fig.1.1
GHG Emission

Transportation sector greenhouse gas emissions, Canada, 1990 to 2015 approximately more than a hundred million car tires currently are in-use in Canada. This encourages manufacturers and policy makers to think about more environmentally friendly and efficient cars to compete with similar ones. Therefore, it is important to consider every part of the vehicle to determine which part could be improved. In the year 2020, the government of Canada is committed to reduce GHG emission to 130 megatons (Mt) lower than to those in 2005. The government regulation, restrictions regarding pollution control, as well as customer's trends to eco-friendly products, has driven manufacturers to develop sustainable products. Identification of environmental impact would be the first step to generate greener products. Decreasing GHG emission and harvesting waste energy are two
important reasons that cause thinking about vehicle tires and their impact on the environment. Vehicle tires experience periodical normal and shear loads under dynamic conditions. This load can be used as a source of mechanical stress for piezoelectric harvesters. The use of piezoelectric devices installed in pneumatic tires will enable the capture of kinetic energy from vehicle weight. This energy can be used to power other parts of the vehicle to save the fuel consumption such as low power electronics. This kind of energy shows potential as a power supply compared to batteries with a short lifespan.

LITERATURE SURVEY

[A] ENERGY HARVESTER MOUNTED ONA SHOE

A Moonie harvester is embedded inside the shoe (see Figure 3.1) to estimate the amount of harvested energy because of heel presses. The "Moonie," is a metal ceramic composite transducer that has been developed by sandwiching a Poled lead Zirconate Titanate (PZT) ceramic (PZT-5H) between two specially designed metal end caps. The energy output of one step was recorded as 81 µJ which translates to 162 µW for two shoes when walking 2 steps per second. The power density at 1 step per second frequency was measured as 56 $\mu W\ cm3$.

Fig.2.1
Shoe Measurement System

[B] POWER GENERATION FROM PEDESTRIAN FOOTSTEP

A company has completed over 100 projects around the world, across various sectors including train stations, shopping centers, airports and public spaces. Figure 2.2 & 2.3 shows some projects which were performed by this company.

Fig.2.2
Omer Train Station, Northern France

Fig.2.3
Federation Square, Melbourne

This new technology captures energy from footsteps fooling on it and a combination of electromagnetic induction and flywheel energy storage technologies with capability of producing 7 watts of electricity from one person walking across a short space.

[C] DANCE FLOORS

A similar project was performed in London by the Club4climate project which produces electricity with dancers jumping up and down which charges some batteries. This club produces 60% of the energy needed by the clubber's movement.

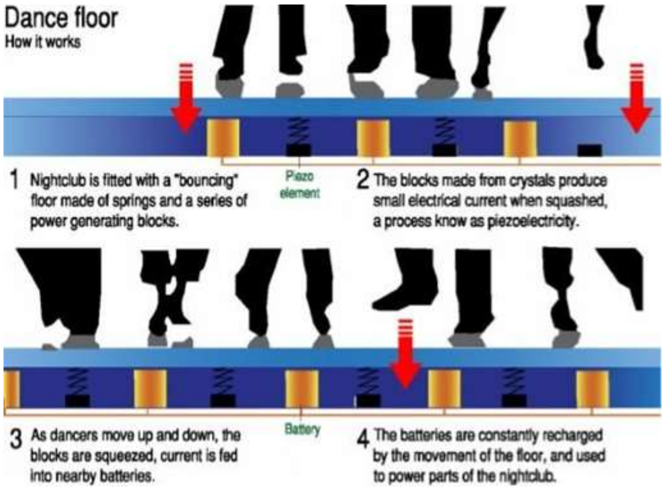

Fig.2.4
Piezoelectric Flooring System Generates electricity through Kinetic Energy

[D] PIEZO-HARVESTERS EMBEDDED IN RAIL-WAYS

The first try of installing piezoelectric IPEG pads on the rail track was done by Innowatchtech Inc [18]. an Israeli company. The experiment was conducted on the railway with ten-car train weight. Achieved results demonstrate that around 120 kWh could be produced which is enough to power light and signs, and other surpluses that can be routed to the grid (see Figure 2.5).

Fig.2.5
Installing Piezo IPEG Pads

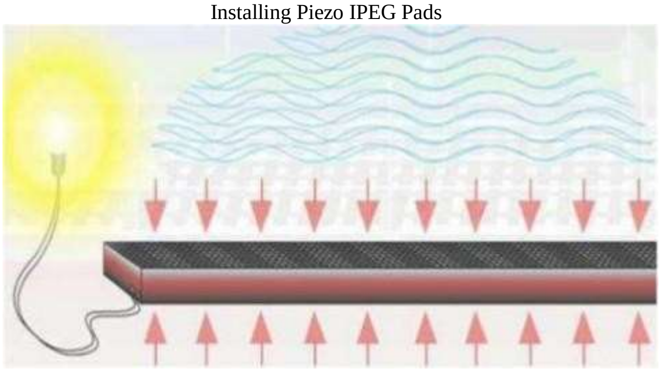

Fig.2.6
Piezo IPEG Pads' Function

[E] PIEZO-SMART ROADS

Transportation on highways and roads play a significant role in economy and society development. Currently, the speed of energy consumption is more than the speed of regenerating it. Therefore, to have more sustainable and reliable types of energy, it is required to think about some new technology to
supply power. Almost all people need to use roads and highways very often such as taking buses or riding in cars. According to research, the transportation sector consumes almost one-third of the nation's energy. Inno watch Inc Was the first company which worked on the harnessing energy from the roads. According to Henderson, piezoelectric crystals embedded in the asphalt can generate up to 400 kilowatts of energy from a 1 kilometer stretch of generators along the dual carriageway (assuming 600 vehicles go through the road segment in an hour), enough energy to power 600-800 homes. The energy generating road offers a self-sustaining environment for the future.

Fig.2.7 Smart-Road

III. METHODOLOGY:

To generate electricity from running cars, the most suitable place must be chosen to put the piezoelectric materials. In the research performed by Makki and Pop-Iliew, piezoelectric materials were installed inside of the tire. The pressure inside of the tire is slightly less than the pressure outside of the tire surface. To claim this statement, imagine pressure represented with Pi and contact patch area with A, then force on the ground is $Fi = Pi \times A$. On the other hand, tires have some elasticity. Deformation of the tire because of weight creates an elastic force according to Hooke's law. This force is Fe for tires. Therefore, the total force on the ground is:

$$Fg = Fe + Pi \times A$$

So, outside of the tire is a more appropriate candidate to install piezoelectric materials than the inside.

Some materials like quartz, biological materials like bone, DNA, and various proteins have piezoelectric properties. At first, it was designed to use a virus as the piezo material. This choice is in nature and could not damage the environment which is one of the goals of this project (sustainable development). Then, because of healthand safety issues, it was changed to PZT. The PZT is described in previous chapters. In this project four main criteria were considered to choose the piezoelectric materials.

At first a Parmatex weather-strip adhesive was selected to bond piezoelectric elements to the tire. This was a better choice because of flexibility, excellent adhesion to rubber and metal. However, to simplify changing the piezoelectric, 5 cm strip bonders were used. These strips facilitated the work to change the piezo element for each speed.

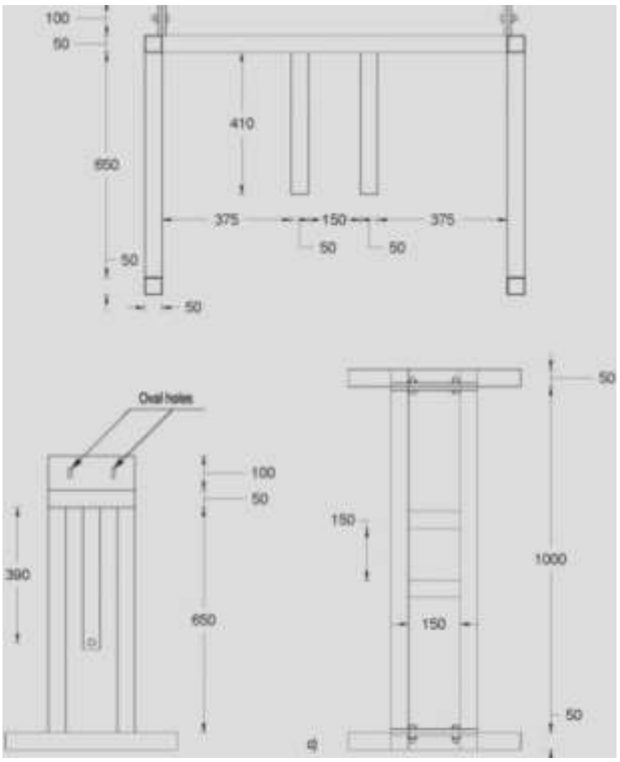

Fig. 3.1
Specifications of Steel Frame

PIEZOELECTRIC ARRANGEMENT:

Figures 3.2 show the layout of piezoelectric elements in five pairs and connect with the control circuit. The tire was 23 cm in diameter; hereforeust 10 piezoelectric elements are used for this experiment. On the other hand, piezoelectric elements require a breakout two by two, and wooden pad dimensions would not allow using more than five which is used in this project. The produced power amount is a function of piezoelectric materials which are connected in parallel to each other. Later, in the discussion section, it will be shown why these elements were in parallel not in series. All piezoelectric pairs were connected in parallel to each other and all of them, then, were connected to the breakout board. The function of the breakout board is described latterly. Piezo elements are attached to the tire symmetrically. Therefore, charge and discharge time for all of them is equal. Tire surface was sanded with sandpaper to remove all roughness, then, one rubber tube was bonded to the tire with the Parmatex weather-strip adhesive. Creating a rubber based patch allowed easy assembly for attaching and removing the piezoelectric without contributing towards power generation.

Fig.3.2

Piezo Elements Mounted on Wheel

Fig.3.3
Control Circuit

The piezo elements are capable of bending more in a concave manner i.e. with the ceramic on the inside of curvature rather than on the outside (convex). Figure 5.4 shows the concave and convex deformation of PZT elements. As said before, to bond the piezoelectric elements to the rubber, an adhesive bond was used to increase bend ability of piezoelectric materials and feasibility of assembly of them and prevent PZT layer damage. This technique ensures optimal concave deformation while significantly reducing convex deformation.

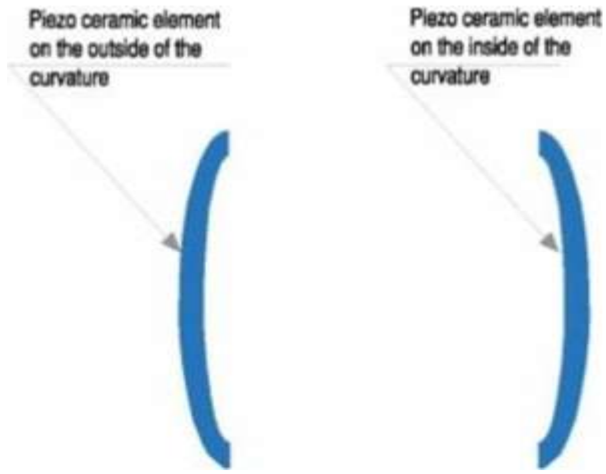

Fig.3.4
Different Deformations of Piezo Elements

OUTPUT CALCULATIONS:

Since the vehicle weight is 1400 kg and it is supposed that the weight is distributed equally between tires, the load on each tire was calculated be350g (3433.5 N). As it is mentioned earlier, pressure and frequency were constant. Therefore, according to Figure 6.1, force is 332 N for the scaled down model and contact patch area A:

$$A = \frac{Force\ on\ each\ wheel}{Pressure\ under\ tire} = \frac{332}{0.17} = 1952.94\ mm^2$$

By considering the tire width, the contact patch length is 55 mm. This area is sufficient for two piezoelectric elements in two arrays, where σ is the mechanical stress in thepiezoelectric element, t is piezoelectric thickness and d33 represents the charge coefficient which is described earlier.

$Charge\ per\ \ each\ piezo\ \ elemnt = \ Charge\ density \times area\ of\ each\ piezoelement$

$$Charge\ per\ each\ piezo\ elements = 0.0595 \times \pi \times 0.012^2 = 0.027\ \mu C\ or\ \frac{\mu A}{s}$$

$$Charge\ density = d_{33} \times \sigma = 350 \times 10^{-12} \times 170000 = 0.0595\ m\ \frac{C}{m^2}$$

Power output = V × I = 1.29 × 0.027 = 0.035 μW/s

This amount is the output power for one piezo element in the scaled model in the pneumatic tire. A real model tire is 205/70R15. To find out how much power would one Chevrolet Malibu generate, the model needs to be scaled up to the reference vehicle. All specifications of this car are shown. Assuming a 20 mm gap between the elements, and the tire circumference and width, thenumbers of elements which can be placed are:

The reference tire width was 250 mm, which provides enough room to place 4 piezo elements in a row. Average voltage in the scaled down tire was 1.29/piezo element. Now, if all 4 piezo elements are connected parallel, the voltage output adds up to 1.29 × 4 = 5.16, and power output is 0.18 mW. For one complete rotation, the amount of powergeneratedintotalisequalto0.18× 56 = 10.11 mW/s. This amount of output depends on how to connect the other piezo elements to each other. Assuming that the vehicle runs at a speed of 90
km/h, and then the number of rotations per second is calculated with the RPM equation which is shown above. This amount can be increased with different models of connection between piezoelectric in circumference or rectifiers to add up the total voltage. Therefore, the output powerfor each wheel in per second is 9.7×10.11=
98.1. If this vehicle runs for one hour, then the amount of energy can be harvested is equal to 98.1 × 3600 =
0.35 W for each tire and 1.4 W for the whole car. This amount of energy is low for this time development of piezoelectric materials, but, this is

a sufficient proof of future work for this new technology to run abroad electronics. Energy harvested from piezo benders depends on RPM and weight of vehicle. Different sizes of vehicles can produce different amounts of power. This method is sufficient for heavy vehicles with small diameters. Because according to the pressure formula (P=F/A), by increasing F and decreasing A, this results in higher pressure and more power generation. Each piezoelectric element experiences two different modes: first, when the piezoelectric element places underneath of load which is named open-circuit mode, and second is the bending situation before and after the contact patch. Open-circuit voltage amount can be achieved from this formula:

$$v = \frac{g_{33} \times F \times h}{\pi \times r^2}$$

Where,

r = outer diameter of piezoelectric; h = thickness of piezoelectric;
g33 = voltage constant.

For the piezo elements used in this study, the factors r and h, are 40 mm and 23 mm, respectively. The voltage constant g33 is 25 × 10- 3 V .mm/N,

$V = 25 \times (10)^{\wedge}(-3) \times 332 \times 0.23 / (\pi \times r^{\wedge}2\ ) = 1.3$ V

The amountof power produced because ofrevolution of tire calculated before:

P1 = 0.35 w

and power at open-circuit situation is:

P2 = V × I × n = 1.3 × 0.027 × 56 = 1.96 w

Where, n denotes the number of piezo elements. Finally, the total power is:

P = P1 + P2 = 1.96 + 0.35 = 2.315 w

CONCLUSION

The technology is expected to make more contributions for the future exploitation and with further reduction in its cost, due to the rapid breakthrough through material developments, design innovations as well as the manufacturing revolutions. The work presented here draws a solid starting line for the widespread use of piezoelectric harvesters in the near future. Consequently, the following recommendations are suggested for future work from the experience of work:

There is a limitation in the selection of PZT elements because they are more fragile and may damage after a while. New developments in the PZT which have more potential to resist cyclic loads are required.

- The storage system for the generated power needs more investigation. Rechargeable batteries are an option.
- The generated power may be low to date. However it can be used for small parts of vehicles if stored. This application for small energy is not defined.
- The need for energy harvesting technology in the field of self-powered systems remains on emerging intelligent tire technology which captures waste energy and converts it to electricity by means of piezoelectric specifications.
- Improvement is required to apply this system to a wireless system.
- It is necessary to assess the emissions emitted during production, use and end of life process (land filling, recycling,) of the piezoelectric materials in the air, soil, and water in detail.

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