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Review Article

Self-sustaining super car

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Abstract

There is an ever increasing demand for energy due to the growth of population across the world. This scenario necessitates alternative, efficient and sustainable energy sources to serve the current needs, without affecting abilities to meet future generation's needs. Piezoelectricity is a widely researched sustainable energy source. Various forms of piezoelectric materials have been used to harvest the energy from vibration, repetitive strikes and bending of structures. This paper discusses different piezoelectric materials used in tires of commercial vehicles to harvest energy that can be used to charge batteries to power the vehicle and its electric sensors. Different techniques of energy harvesting are explored using the highly bendable piezoelectric elements including PVDF and PZT. The energy harvesting relies on the deformation of tire's tread-walls and side-walls when the vehicle's weight acts on it. The adopted methods are compared to analyse their effectiveness in terms of power production capacity.

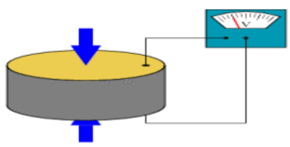
Keywords: piezoelectric, self-sustaining car, deformation of tyre.

1. Introduction

Alternative energy will become increasingly important as fossil fuel supplies inevitably run out or environmental damages spark consumer awareness. The search for a viable energy alternative will continue until this alternative can address the dynamic demands of the electrical grid and storage limitations. Energy harvesting within the tire has been of great interest in the recent past. This energy can be used to drive the vehicle if harvested with maximum efficiency thereby eliminating the need of non-renewable energy sources. Some interesting ideas have emerged utilizing piezoelectric elements to harvest energy through vibration, impact, and bending of such elements.

1.1 What is Piezoelectric effect?

Piezoelectric effect is the ability of certain materials to generate an electric charge in response to applied mechanical stress.



The piezoelectric effect is understood as the linear electromechanical interaction between the mechanical and the electrical state in crystalline materials with no inversion symmetry. The piezoelectric effect is a reversible process in that materials exhibiting the direct piezoelectric effect (the internal generation of electrical charge resulting from an applied mechanical force) also exhibit the reverse piezoelectric effect (the internal generation of a mechanical strain resulting from an applied electrical field). For example, lead zirconate titanate crystals will generate measurable piezoelectricity when their static structure is deformed by about 0.1% of the original dimension. Conversely, those same crystals will change about 0.1% of their static dimension when an external electric field is applied to the material. The inverse piezoelectric effect is used in production of ultrasonic sound waves.

1.2 Working

The nature of the piezoelectric effect is closely related to the occurrence of electric dipole moments in solids. The latter may either be induced for ions on crystal lattice sites with asymmetric charge surroundings (as in BaTiO3 and PZTs) or may directly be carried by molecular groups (as in cane sugar). The dipole density or polarization (dimensionality [Cm/m3]) may easily be calculated for crystals by summing up the dipole moments per volume of the crystallographic unit cell. As every dipole is a vector, the dipole density P is a vector field. Dipoles near each other tend to be aligned in regions called Weiss domains. The domains are usually randomly oriented, but can be aligned using the process of poling (not the same as magnetic poling), a process by which a strong electric field is applied across the material, usually at elevated temperatures. Not all piezoelectric materials can be poled.

Of decisive importance for the piezoelectric effect is the change of polarization P when applying a mechanical stress. This might either be caused by a re-configuration of the dipole-inducing surrounding or by re-orientation of molecular dipole moments under the influence of the external stress. Piezoelectricity may then manifest in a variation of the polarization strength, its direction or both, with the details depending on 1.The orientation of P within the crystal, 2. Crystal symmetry and 3.The applied mechanical stress. The change in P appears as a variation of surface charge density upon the crystal faces, i.e. as a variation of the electric field extending between the faces caused by a change in dipole density in the bulk. For example, a 1 cm3 cube of quartz with 2 kN (500 lbf) of correctly applied force can produce a voltage of 12500 V.

2. Deformation of tire

A tire under no load maintains its circular shape as shown in Figure 1 (a). However, under the load of the vehicle a section of the tire Treadwall conforms to the shape of the road i.e. flattens out into an area known as the Contact patch. This section of the Treadwall within the Contact patch is deformed from its regular circular shape. Moreover, the area of the Sidewall just above the contact patch also undergoes deformation i.e. bulges out and the effective Section Height of the tire decreases, Figure 1 (b). 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. The deformation of the Treadwall and the reduction in the effective Section Height due to the deformation of the Sidewall presents an opportunity for energy harvesting through the use of piezoelectric bender elements that would deform and relax with the tire.

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

3. Pzt bender bonded to tire

Very thin and flexible PZT unimorph elements are bonded to the inner liner of the tire opposite to the treads. The brass reinforced elements have a total thickness of 0.23 mm with a 0.1 mm thick circular ceramic plate of 25 mm diameter; Figure 2 (a). A 185/65R14 passenger vehicle tire requires 3.5 mm of end-to-end deformation for a 40 mm element which is beyond the capacity of many PZT benders available in the market. However, the PZT elements used in this paper and previous research 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 as shown in Figure 2 (b) 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.

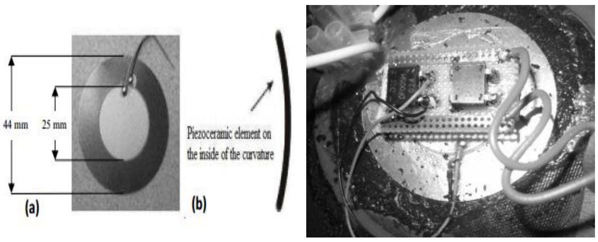


Fig. 2: (a) Size of PZT element [6] and (b) One-sided bendability of the PZT element

Figure 2 (c) shows the circular element bonded to the tire atop a tire circular tire repair patch. 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, Figure 3 (a). 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. The graph of power output from PZT bender at different load resistances is also presented in Figure 3 (b). 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.

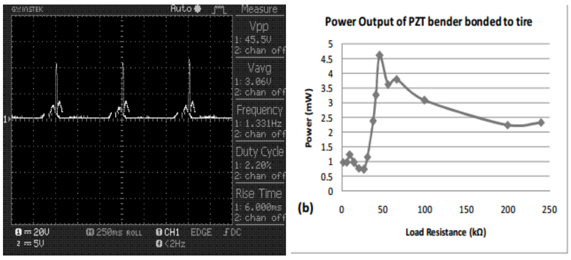


Fig. 3: (a) Voltage peaks produced by PZT upon each deformation, and (b) Power delivered to various resistive loads

4. PVDF bended bonded to the tire

PVDF elements are composed of a thin PVDF sheet with electrodes on either side. Aftermarket ready-to-use PVDF elements were acquired from Measurement Specialties Inc. in the form of 216 x 280 mm sheets. These sheets and subsequently the elements developed from it are 110 µm in thickness with silver ink electrodes on either side. These elements without any additional reinforcements can only be used in high frequency vibration mode. To be able to utilize the low frequency (less than 20 Hz) deformations pattern of the tire for power generation the PVDF elements have to be bonded to a reinforcement layer e.g. a plastic or brass sheet. There have been several previous publications that describe the need for such a reinforcement and thus will be omitted in this paper. A 100 µm thick 40 x 40 mm square element, Figure 4 (a), bonded to a 0.3 mm plastic sheet is used for this research to provide reinforcement and preserve the flexibility of the PVDF element. This element was bonded to the tire using the same adhesive as described in the previous section, Figure 4 (b). Figure 5 (a) shows the peak voltage generated by the element at a rotational wheel speed of 80 RPM. A peak voltage of 62.3 V and an average voltage of 1.0 V is generated at no load.

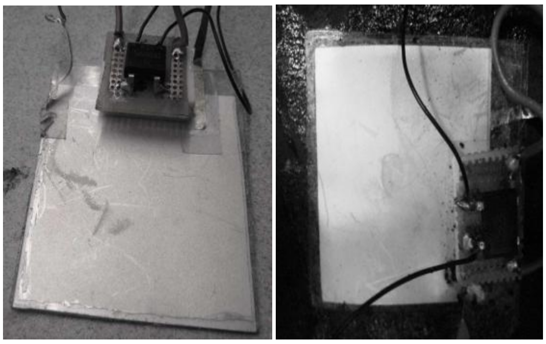


Fig. 4: (a) 40 x 40 mm PVDF element with rectifier circuit attached on top, and (b) the same element bonded to the tire

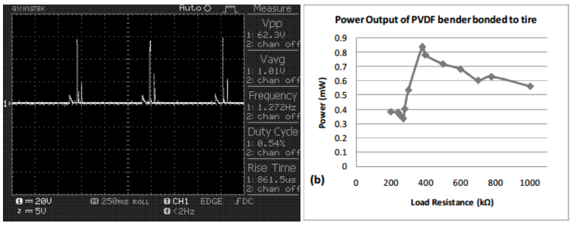


Fig. 5: (a) Voltage peak generated by PVDF element at each revolution, and (b) resulting power output for various load resistances.

The power output delivered by the PVDF bender to different loads is presented in Figure 5 (b). A peak output of 0.85 mW is produced by the element at a high load resistance of 380 k_, very less when compared to their PZT counterpart. However, PVDF elements being a lot more flexible present themselves as a more suitable candidate for high deformation applications such as a tire based power generation. Furthermore, unlike the PZT elements PVDF elements can handle deformation in either direction without suffering physical damage. Lastly, PVDF elements have minimal impact on the deformation pattern of the tire due to their inherent flexibility. Besides lower power output, PVDF elements also have lower operating temperature of 100 ‘C or below and undergo permanent loss in polarization when the temperature negatively affecting their power output capacity.

5. PVDF ribbon attached to the tire bead

This novel method of energy harvesting does not use the deformation of the tire, as described earlier, directly as it does not involve the bonding of piezoelectric element on the deformable part of the tire. Instead it relies on the deformation of a plastic ribbon bonded to the rigid bead section of the tire due to the changing tire Section height – the height of the Sidewall of the tire. As stated earlier, the Sidewall deforms and reduces in the overall height just above the contact patch due to the weight of the vehicle, Figure 1. As the wheel rotates the Sidewall and consequently the ribbon relaxes and deforms; effective Section height increases and decreases in a cyclic pattern. The attachment of three (3) PVDF element (blue) ribbon (red) on to the tire (black) is depicted in the graphic illustration in Figure 6 below. The ribbon is only bonded to the rigid Bead of the tire at points A and B while the remainder of the ribbon rests freely on the Inner liner of the tire as shown. The space between the ribbon and Inner liner of the tire Sidewall is also evident. As the Sidewall deforms under the weight of the vehicle; the Section width of the tire increases while the Section height decreases, the ribbon also deforms and moves closer to the Sidewall while getting squished vertically. The PVDF elements are placed at the location of maximum ribbon deformation and thus produce power with each revolution of the wheel by deforming with the ribbon.

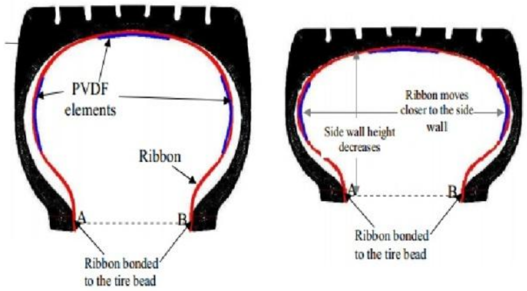


Fig. 6: Graphical Illustration of the change in the Section Width and Section Height of the tire and the consequent deformation of the ribbon bonded to the Bead of the tire.

The 20 x 270 mm ribbon is shown in Figure 7 (a) with four (4) PVDF elements bonded to it. The ribbon used in the actual experiments is of the same size but has three (3) elements attached to it in a similar pattern Figure 7 (b).

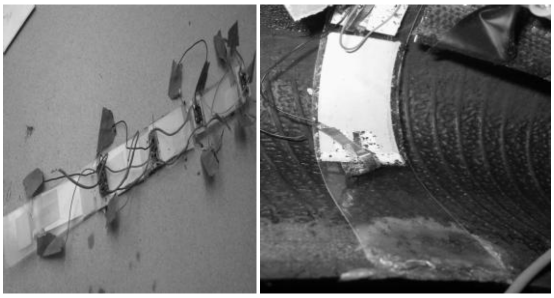


Fig. 7: (a) A 20 x 270 mm plastic ribbon with four (4) PVDF elements and rectifier circuits, and (b) A plastic ribbon with three (3) PVDF bonded to the Bead of the tire from side to side.

Figure 8 (a) shows the peak voltage of 18.7 V generated by the ribbon, whereas Figure 8 (b) presents the graph of power output from the ribbon for various resistive loads with a maximum output of 0.23 mW for a load resistance of 400 k_ at 80 RPM. The Ribbon produces the least amount of power compared to the two previous methods but has significant advantages over them as discussed next.

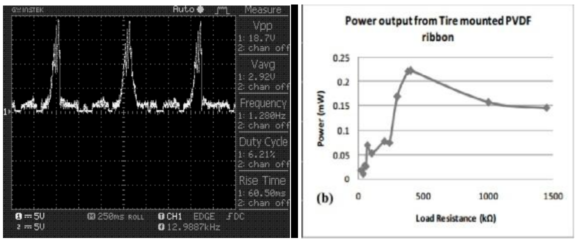


Fig. 8: (a) Voltage peaks generated by the ribbon, and (b) Power delivered to various loads

6. Advantages of mounted PVDF elements in this manner include

1) Damage prevention – since the PVDF elements or the ribbon in not bonded to the Tread wall or sidewalls, chances of damage due to tire puncture or other penetrable foreign objects is greatly minimized

2) Minimized effect on the deformation of the tire – The ribbon is bonded to the rigid bead section of the tire bearing steel wires that do not undergo deformation. Since no deformable areas of the tire are affected, the overall deformation characteristics of the tire remain unchanged and the safety rating of the tire unaffected.

3) Damage free removal of the Ribbon – Bonding PVDF and PZT directly onto the tire poses difficulty of their removal at the end of tire's service life. This is because the elements may be subjected to higher deformation than they can undergo during the removal process rendering them unusable. In case of a ribbon the bonding point is located conveniently away from the elements allowing easier removal without damaging the actual elements.

7. Duel-battery super car

The energy harvested by piezo electric extraction from tires can be used to drive the vehicle. Maximum output can be generated by strategic placing the piezo electric material within tires.

A duel power source arrangement is needed to execute the working of the Self Sustaining Super-car. The duel sources are initially charged to their full capacity. When the car starts, one of the sources is used to propel the vehicle. Once the charge on the first power sources reaches a pre-set threshold value, the second power source takes over. While the second power source is driving the vehicle, the first power source is charged using the power generated from the tires, and the same process is repeated.

However, the power generated through this method is less than the power consumed, and thus, the vehicle is bound to run out of power eventually. Extensive research and study to enhance the power extraction from vehicle tries using piezo electric materials may lead to highly-efficient and 100% self-sustaining super vehicle.

References

[1] http://www.eaa-phev.org/wiki/Plug-In_Hybrids Plug-in hybrid electric vehicles. Accessed 2 February 2011.

[2] Keck M., A new approach of a piezoelectric vibration-based power generator to supply next generation tire sensor systems, *IEEE Sens*2007:1299-1302. doi:10.1109/ICSENS.2007.4388648

[3] Pinna L., Valle M., Marco G., Experimental results of piezoelectric bender generators for the energy supply of smart wireless sensors, *Proc.*

13th Italian Conf. Sens. Microsyst., pp. 450-455, World Scientific, 2008. doi:10.1142/9789812835987_0074

[4] Makki N., Pop-Iliev R. Piezoelectric power generation for sensor applications: design of a battery-less wireless tire pressure sensor, *SPIE Proc.* 8066, 806618, 2011. doi:10.1117/12.887112

[5] Wu, L., Wang, Y., Jia, C. and Zhang C. "Battery-less piezoceramics mode energy harvesting for automobile TPMS". IEEE 8th International Conference on ASIC. doi: 10.1109/ASICON.2009.5351190

[6] Manla, G., White, N.M. and Tudor, J. "Harvesting energy from vehicle wheels. SolidState Sensors, Actuators and Microsystems". Transducers 2009. doi: 10.1109/SENSOR.2009.5285831

[7] Khamendeifar, F. and Arzanpour, S. "Energy Harvesting From Pnuematic Tires Using Piezoelectric Transducers". ASME Conference on Smart Materials, Adaptive Structures and Intelligent Systems, *ASME* 2008. doi: 10.1115/SMASIS2008-426

[8] Makki, N. and Pop-Iliev, R. "Pneumatic Tire-based Piezoelectric Power Generation". Proceedings of SPIE Smart Structures/NDE. doi:10.1117/12.880636\

[9] Jazar, R.N. "Chapter 2: Vehicle dynamics: theory and applications". Springer. pp. 379- 451.

[10] Piezo Buzzer Element. Cui Inc.

[11] http://products.cui.com/adtemplate.asp?invky=6860&brand=electroniccomponents&catky=523311&subcatky1=396557&subcatky2=353588&subcatky3=.Accessed 10 September 2010.

[12] PVDF Piezoelectric film sheets. Measurement Specialties, http://www.measspec.com/piezo-film-sensors/piezo-film-sheets.aspx. Accessed August 2010.

[13] Piezoflex Polymer. Piezoflex. http://www.airmartechnology.com/uploads/AirPDF/Piezoflex.pdf. Accessed September 2010. Accessed September 2010