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PRISTINE MECHANICAL ENERGY CONVERTERS

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ABSTRACT

This paper deals about the conversion of unused or waste mechanical energy into electrical energy using piezoelectric materials. Some of the unused mechanical energy are human walking, rotational movements of automobile parts in vehicles, pressing force applied in keyboards, etc. These unused mechanical energy are harvested by piezoelectric materials for generating electrical energy. The generated electrical energy is used for various purposes (Automobiles battery charging, Laptop charging, Street lighting etc).

Keywords: *Pristine, Piezoelectric Materials, PVDF, Polymers and Power Tracks*

1. Introduction

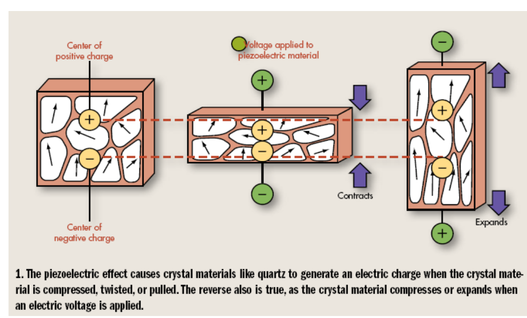
This paper deals about the method of generating power from the unused mechanical energy. The power generated from the conventional resources are emptied at a much faster rate than they are replenished. So it is necessary to adopt another power source preferably non-conventional energy source to reduce pollution and power demand. Recent developments have been made in harnessing the unused mechanical energy for generating electrical energy. Piezo-electric materials have the capability of harvesting energy from mechanical vibrations in a dynamic environment. Unused power exists in various forms such as walking, frictional parts of automobile, vibration in pavements while walking, vibrations in roads and bridges etc. These energies are converted into electrical energy by piezoelectric materials. The power generated by this materials are used for charging/feeding the low power consumption systems like mp3 players, mobile phones, automobile batteries, GPS receivers or sensors of remote sensing systems or transmitters which are conventionally powered by batteries.

Polyvinylidene fluoride (PVDF) piezoelectric polymer materials are used commonly due to its flexibility and strength. The advantage of piezoelectric power supply is ecological, embedded and it does not require any maintenance. Piezoelectric polymers are commercially available and are relatively inexpensive.

2. Sources of Energy

2.1 Walking

Walking is a huge mode of transportation. People walk for so many reasons: to buy groceries, for shopping, local transport, to go to nearby places, for fitness and so on. Walking is one of the exercises, which involve quite a lot of our muscular energy. Many people walk as a hobby, and in our post-industrial age it is often enjoyed as one of the best forms of exercise. An average walking speed is about 6 to 7 km/h (3 to 4 mph).



1. The piezoelectric effect causes crystal materials like quartz to generate an electric charge when the crystal material is compressed, twisted, or pulled. The reverse also is true, as the crystal material compresses or expands when an electric voltage is applied.

Fig. 1 Piezoelectric Behavior

2.1.1 Walking statistics

The Ramblers formerly known as the Ramblers' Association, is the largest walkers' rights organisation in Great Britain, which aims to look after the interests of walkers (or ramblers). It is a charity registered in England and Wales, with around 135,000 members. There are 485 Ramblers' groups in about 50 areas, and around 350 other affiliated bodies, such as societies especially interested in the heritage of the countryside, the Footpath Society, and local councils.

The statistical data about the walking community of Great Britain is issued by its Department of Transport.

There are many people who make walk trips to visit their nearby houses or places. The chart showing

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the walk trips made by the men and women of Great Britain in a year:

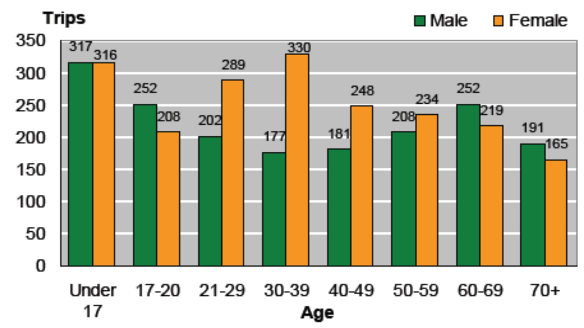

Fig. 2 Data Indicating the Walk Trips of People of England

The total distance walked by the men per year in Great Britain is 192 miles i.e. 308.99405 kilometres. A normal man in a kilometre takes about 3000 steps. So, approximately 9,27,000 steps and the total distance walked by the women per year in Great Britain is 201 miles i.e. 323.57814 kilometres. A normal man in a kilometre takes about 3000 steps. So, approximately 9,70,000 steps. Totally, through walk trips alone we get around 19,00,000 steps in Great Britain alone. The stress exerted on each of these step could be harnessed using our Powershoes. If U.K. alone constitutes this much energy means, the walking power around all over the globe could be harnessed and can be used as a good fuel.

2.2 Roads

The following chart will show the tendency of people towards walking as years roll on. It could be found out that the tendency of the people towards the walking decreased. People use cars to reach even nearby places almost 58% people use cars to reach the distances within mile. Hence the usage of roadways also gets increased.

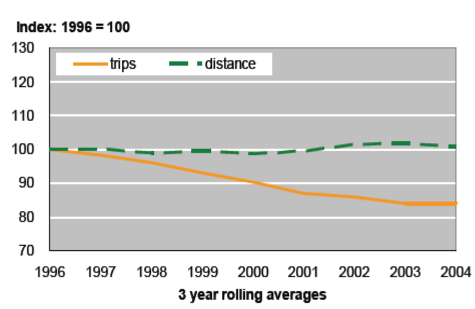

Fig. 3 Comparision of Travel by Walking and Through Roadways

2.3 Similar Issues

There are similar concepts harnessing energy from unused mechanical energy. Some of them resembles and related to our idea

Piezoelectric Road:

We can develop a way to recoup the pristine energy from cars operating on public roadways. Using piezoelectric materials installed under the asphalt, highway vibrations are converted into a staggering amount of electricity. It is possible to cultivate electrical energy from the unused mechanical energy up to 500 kilowatts from a busy four-lane road per kilometer. It is enough to power about 100 homes.

Capacity:

The generating capacity of piezoelectric devices can be crudely over-approximated by assuming that the vibrations in the road are caused by traffic alone, and that each "vibration event" from one vehicle is independent of another (i.e. the vibrations are sufficiently dampened before the next vehicle passes). Under these assumptions, the total energy harvested by piezoelectric devices along a one-kilometer stretch is at most the number of cars that pass multiplied by the vibrational energy that one car transfers to the road. This vibrational energy can be over-approximated by the energy that each car consumes and puts to mechanical work across this stretch. In other words, the energy a car loses to vibrations in asphalt must be less than the energy a car puts to mechanical work over the one-kilometer stretch. This value can be computed by multiplying the energy consumed from gasoline by thermal efficiency.

$$\text{Expended Energy} = (\text{Gasoline Used}) \times (\text{Energy Density of Gasoline}) \times (\text{Thermal Efficiency})$$

$$= \frac{1\ \text{km} \times 0.621\ \text{mi/km} \times 2.8\ \text{kg/gal} \times 4.43 \times 10^{7}\ \text{J/kg} \times 0.4}{20\ \text{mi/gal}}$$

$$= 1.54\ \text{MJ}$$

This overestimation provides an appropriate upper bound to the amount of energy absorbed by piezoelectric devices from one car moving across a one kilometer strip (i.e. no more than 1.5 MJ). Of course, some of this "mechanical" (i.e. non-thermal) energy is lost as various forms of friction and used for other processes inside the vehicle (such as air conditioning), and not nearly all of the vibrational energy will be absorbed by the devices in the road. If the devices are embedded on a busy street, then such a street will generate at most this amount of energy multiplied by the number of cars moving across the street. If such a street or highway sees an average of 600 vehicles per hour (as assumed by Innowattech), then the energy provided by these devices on a one-kilometer stretch could power at most 105 Western-U.S. homes (with a total of 257 kW). [1,2] If the calculation were repeated for only 18-wheelers (with about 5 mpg), the maximum amount of homes a one-kilometer strip could power would increase to 421 homes (with 1 MW).

However,a more reasonable approximation can be made by using the fact that approximately 5% of the energy consumed by the car is lost as rolling friction, although rolling friction accounts for both internal friction in the wheels and friction due to the asphalt. [5] By replacing thermal efficiency in the above equation with 5%, the amount of energy released into the ground for one 20 mpg car would decrease to 0.19 MJ. This one-kilometer strip could then power at most 13 homes (32 kW) for the 20 mpg car, or 52 homes (128 kW) for an 18-wheeler. For this calculation, there is still a major assumption that all the vibrational energy of the road is captured by piezoelectric devices.

It is nor t clear whether the numbers currently used to quantify generating capacity are misguided or simply misreported, but under the optimistic assumptions stated above, piezoelectric devices over a one-kilometer strip of road will generate power for only about 15 homes. Unless the road carries only 5 mpg vehicles (or many more than 600 vehicles per hour), it is unlikely that anywhere near 400 kW of power can be generated from one kilometer.

Profitability

With the price of gasoline hovering around $4 a gallon for the past year, the cost of driving a 20 mpg car across one kilometer is about $0.124. And by recent retail prices of residential electricity on the West Coast, the 0.19 MJ generated by one car costs about $0.0064, or about one twentieth the cost of the gasoline burned across this one-kilometer strip. [6] At this rate, the road will generate a revenue of $33,565 per year.

As an approximate, the price of a piezoelectric device can be estimated by its most expensive element, namely the piezoelectric component. This component, according to Poly vinylidene Fluoride (PVDF) is about 14×14×2 cm^3 in dimension. Given that piezoelectric sheets of the same material currently cost $165 in bulk from Piezo Systems (for 100 sheets of 10.64 cm^3 each), the cost per cm^3 of this material is about $0.155. Since the devices are embedded 30 cm apart from each other and in two rows per lane, a kilometer of a two-way street will contain 13,333 devices, each device costing $30.39, adding to a total of $405,253. Even without considering the manufacturing or installation costs, it would take about 12 years to earn back this amount from the device revenue.

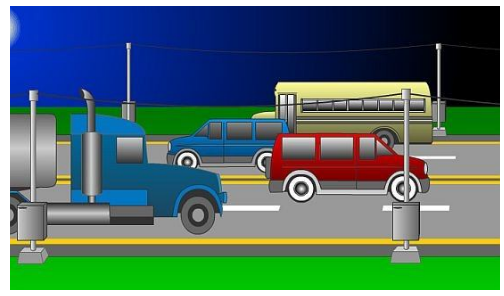

Fig. 4 Piezoelectric Road

1) Piezoelectric shoes: Our concept of piezoelectric shoes involves 0in the placing of piezoelectric sheets inside our shoes so that the stress which is being given on to the shoes while walking, running and jogging could be effectively utilized using the piezoelectric effect. Any people to go anywhere could wear a shoe and there are lot of footsteps made every day by the people. So this is an idea of harnessing the power from each of the footstep.

Fig. 5 Piezoelectric shoes

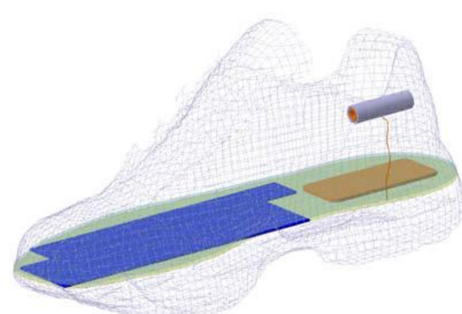

Fig. 6 Power Sole

PVDF was attached to the insole and the strips were connected in parallel. This ensured that all current inputs were added and the voltage input remained at an average of 6V.The assembly process was extremely simplified. The circuit and PVDF were externally connected and were held secure with electrical tape. It explained the introduction of induction system to transfer electrical power through magnetic induction. However, the assembly process incorporated a USB cord that was connected to the output of the circuit. This cord was, in turn, connected to the iPod for energy transfer the piezoelectric strips in the front end of the *Powersole* and the circuit is positioned in the tongue. The circuit is externally connected to the iPod using a USB port. This circuit translates the incoming voltage spikes into continuous DC voltage input for the iPod.

Product Analysis

Based on consumer surveys and observations, the piezoelectric *shoe* is expected to meet certain criteria in Engineering performance and aesthetic and emotional design. This section discusses the analysis performed to ensure that these conditions have been met by the current design.

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PVDF Analysis

This section discusses the development of the formulas for calculating PVDF output based on input and shoe design. The ways in which this material generates power is discussed in the background research section of the report. There are two important equations for understanding this material, which demonstrate how the voltage (*V*) and charge (*Q*) generated are functions of force (*F*), width (*W*), length (*L*), and thickness (*T*) [8]:

$$V = \frac{Fg_{31}}{W}, \text{ where } g_{31} = 216 \times 10^{-3} \frac{V/m}{N/m^2}$$

$$Q = \frac{Fd_{31}L}{T}, \text{ where } d_{31} = 23 \times 10^{-12} \frac{m/m}{V/m}$$

$$Energy = VQ$$

It is important to note that these equations only work for PVDF while it is operating in its range of elastic deformation, which is 2-5 percent elongation [9]. This indicates that the maximum stress that can be safely applied to the piezoelectric material will be

$\sigma = E\varepsilon, E = 2 \times 10^9 \, N/m^2$

$\sigma = (3\times10^9 \, N/m^2) * (0.05) = 1.5 \times 10^8 \, N/m^2 = 150N/mm^2$

Because of its availability and cost, we will be using multiple 40-micron strips of PVDF with dimensions 6.72 inches by 0.86 inches, or 171 mm by 22 mm. We can now calculate how many of these strips we will need to provide the energy to continuously charge an iPod at the rate of a standard wall charger, which is 2.5 watts. Since we know the maximum allowable stress, we can calculate the maximum force allowable that will be applied over the entire area of the PVDF strips. The area depends on the orientation of the strips with respect to the forces, and in our configuration, the tension and compression forces act along the length axes of the piezoelectric strips. This will make the effective area the width times the thickness of the strip, or *WT*. Thus, the maximum allowable force is the stress times the area, or (150,000,000N/m²)*WT*. Since the piezos can be arranged within the ball area of the shoe's midsole to experience the required force, we will use this maximum force in our calculations:

$$F_{max} = (1.5 \times 10^8)WT$$

$$V_{max} = \frac{F_{max} g_{31}}{W} = (1.5 \times 10^8)Tg_{31}$$

$$Q_{max} = \frac{F_{max} d_{31} L}{T} = (1.5 \times 10^8)Wd_{31} L$$

$$Energy = V_{max} Q_{max} = (1.5 \times 10^8)^2 g_{31} d_{31} LWT$$

Plugging in the values $g_{31} = 216 \times 10^{-3}$, $d_{31} = 23\times10^{-12}$, $L = 171mm$, $W = 22mm$, and $T = 40\mu m$, we arrive at the energy equation per strip:

$Volume(m^2) = LWT = (0.171m)(0.022m)(40 \times 10^{-6} m)$

$Volume(m^2) = 1.5048 \times 10^{-7} m^3$

$Energy(J) = (1.5 \times 10^8 \, N/m^2)^2 (216 \times 10^{-3} Vm/N)(23\times10^{-12} \, m/V)(1.5048 \times 10^{-7} m^3)$

$Energy(J) = 0.01682$ N - m

Since we are seeking an energy quantity in watts, we can multiply the above quantity by the frequency *f* (Hz) to obtain joules per second, or watts. We will also consider the goal of reaching the full charger power generation of 2.5 watts, which will be plugged into the left-hand side of the equation. Thus our new equation is:

$Energy(W) = (0.01682J)f$

$2.5W = (0.01682J)fn$

$n = 148/f$

where f is the frequency of steps and n is the number of PVDF strips that are built into the shoe. Using this equation, we can plug in data from a study on footfall frequencies [10]. The average jogger moves at a rate of 150 steps per minute, which is the equivalent of a ten-minute mile.

This indicates that each foot experiences a footfall frequency of 1.25 Hz, which, when incorporated into the above equation, indicates that the total amount of PVDF strips to provide full charging will be 119. Runners who run at a speed equivalent to a seven-minute mile were found to take about 180 steps per minute, or 1.5 Hz on each foot. Taking into account the above energy equation, this indicates a total of 99 necessary strips. This is unreasonable considering the current high cost of PVDF strips at $7 each, which would add around $700 to $850 to the cost of the shoe, just in electronics! Since the iPod battery power charges much more quickly than it is consumed, the Piezoelectric *shoe* will be able to provide charge to an iPod while containing just a fraction of this amount of PVDF.

Future Concepts

It has identified many potential design improvements that can be made to the current product to make it more marketable. For example:

i. **Induction charging with the circuit built into the shoe:** By using induction energy transfer technology (commonly seen in electric toothbrushes), the power generated can be transferred to portable electronic devices eliminating the need for exposed jacks or adaptors. Using this technology the inefficiencies caused due to dust and moisture can be reduced.

ii. **Induction transfer of piezo-generated energy:** Another off-shoot concept of induction transfer is the use of inductors to transfer directly the energy developed by the piezo film to an external circuit. This way the circuit can be built into the adaptor casing and not in the shoe. Cost of the overall product can be significantly brought down as the circuit would be easier to build and package.

iii. **Potential of MEMS and VLSI**: Micro-electro-mechanical Systems (MEMS) is a rapidly developing field. There is already research being done on energy harvesting using MEMS technology. Utilizing these technologies the size and possible the cost of the product can be brought down. Very-Large-Scale Integration (VLSI) is another technology that could bring down the size of the circuit to possibly a single chip, making the circuit more energy efficient. Together using MEMS and VLSI, the density of energy conversion devices per shoe can be significantly improved.

2) Piezoelectric tires: 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.

PVDF ribbon attached to the tire bead

This 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 [11]. 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.

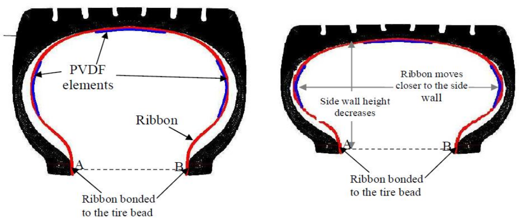

Fig. 7 Graphical Illustration of the change in the Section Width and Section Height of the tire and the consequent deformation of the ribbon bonded to the Bead of the tire.

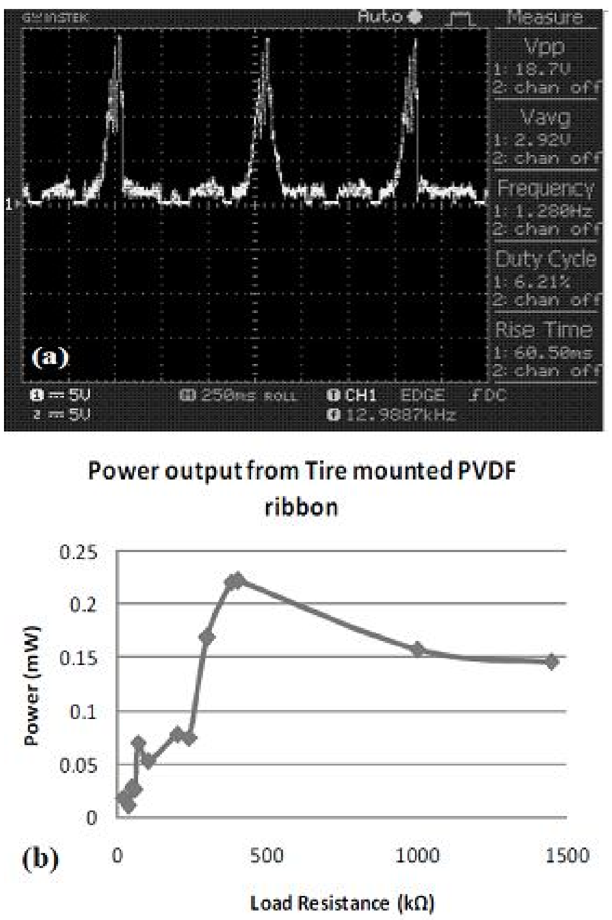

Fig. 8 (a) Voltage peaks generated by the ribbon, and (b) Power delivered to various loads

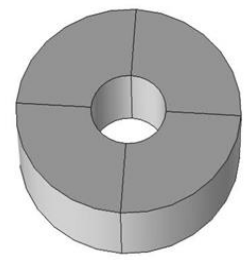

Fig. 9 Tire Rim

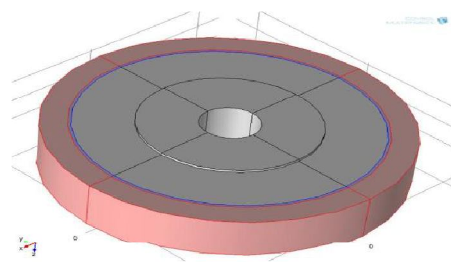

Fig. 10 Piezo Tire

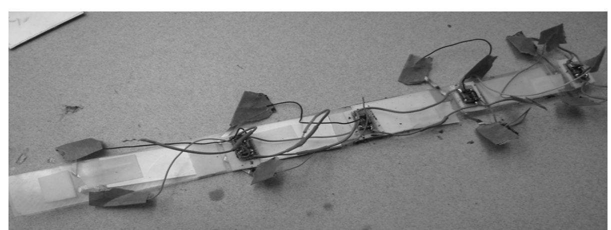

Fig. 11 Insertion of Piezo Material

A thin layer of piezoelectric material with thickness 0.05m is attached around the tire is shown in Fig. 11

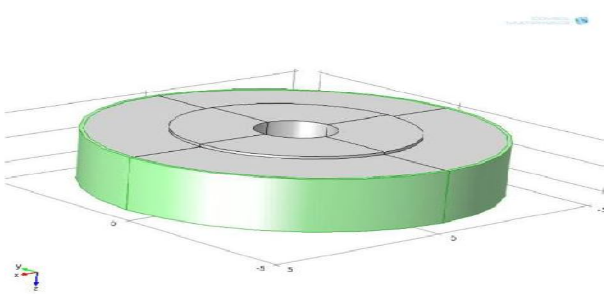

Fig. 12 Piezoelectric Materials in Tire

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.

4) Possibility of mounting sensors on the rim – When the energy harvesting piezoelectric elements are mounted onto the tire, the subsequently powered sensor whether Tire Pressure Monitoring Systems (TPMS) Sensor, Vehicle Speed Sensor (VSS), or Tire Health Monitoring Sensor (THMS) have to be mounted on to the tire as well. However, in case of the PVDF ribbon mounted in close proximity to the Tire-Rim interface the sensor could possibly be mounted on to them rim itself which is the ideal location within the wheel assembly.

3) Piezoelectric Power Station

It is possible to power up the whole area (small region) by collecting the power generated by the piezoelectric roads, piezoelectric railroads and piezoelectric pavements and storing it in a unique station which is known as piezoelectric power station. From the piezoelectric power stations the power is converted and transmitted to various parts of the city/village/area. We can also set up a charging station for charging electrical vehicles.

4) Other Piezoelectric Devices

By using piezoelectric materials it is possible to generate power from presitine mechanical energy of various sources. The following devices are designed to generate and power electrical energy. Some of them are piezoelectric keyboards, piezoelectric railroads, piezoelectric backpacks, piezoelectric mobile phones etc.

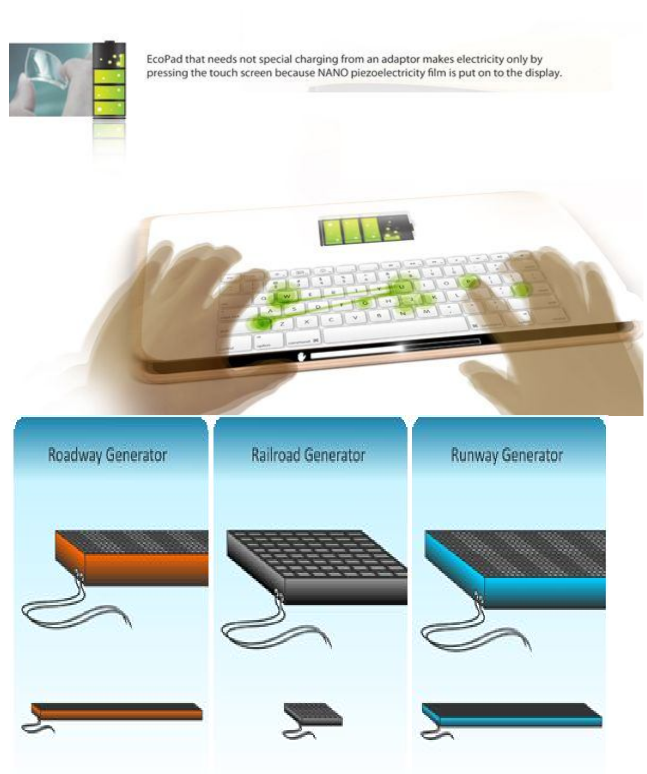

Fig. 13 Piezoelectric Keyboard and Different Piezoelectric Generator Model

3. Conclusion

It is possible to harvest large amount of power using the piezoelectric materials by employing the above mentioned energy harvesting methods wherever the mechanical energy is unused. This kind of pristine mechanical energy converters may reduce the power demand of other conventional energy sources and produce a green energy to our environment.

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