International Journal of Enhanced Research in Science Technology & Engineering, ISSN: 2319-7463
Vol. 2 Issue 6, June-2013, pp: (65-70), Available online at: www.erpublications.com

Piezo-Smart Roads

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Abstract: **In order to satisfy the rising energy demands of global consumption, a new cleaner and renewable power source needs to be explored, conceptualized and developed. This paper intends to introduce an alternative source of energy by using piezoelectric material -a class of smart material. A piezoelectric road that will produce electricity from the stress experienced by the roads due to the movement of automobiles is proposed. The main principle behind this is the piezoelectric effect. The energy is produced from the consumer's participation and it does not require any separate source of input energy.**

Keywords: Smart materials, piezoelectric effect, heavy traffic correlation, pads of metallic crystals, supercapacitor, electric road, mechanism, efficiency, advantage over other sources of energy.

I. INTRODUCTION

Electricity has become a lifeline of present day civilization and thus its demand is enormous and is growing steadily. There seems no end to the different ways one can generate pollution-free electricity. At one hand, rising concern about the gap between demand and supply of electricity for masses has highlighted the exploration of alternate sources of energy and its (energy) sustainable use. On the other hand, traffic on road all over the world is increasing day by day and thus, congestion on roads is becoming inevitable with the fancy of masses towards personal transportation systems for their growing mobility. Energy demand and heavy traffic correlation motivate to dream about a device in the road that would harvest the energy from the vehicles driving over it. For this, piezoelectric material embedded beneath a road, the piezo-smart road, can provide the magic of converting pressure exerted by the moving vehicles into electric current.

The system is based on piezoelectricity, which uses pads of metallic crystals buried over hundreds of meters of road to generate electricity when put under the pressure of quickly moving traffic. With this technology, now, engineers are poised to harvest some of the spare energy of the world's moving vehicles. When a vehicle drives over the road, it takes the vertical force and compresses the piezoelectric material, thereby generating electricity.

II. PIEZOELECTRICITY AND PIEZOELECTRIC EFFECT

The word piezoelectricity means electricity resulting from pressure. It is derived from the Greek piezo or piezein , which means to squeeze or press, and electric or electron , which stands for amber, an ancient source of electric charge.[2] Piezoelectricity was discovered in 1880 by French physicists Jacques and Pierre Curie**.**

The piezoelectric effect is understood as the linear electromechanical interaction between the mechanical and the electrical state in crystalline materials with no inversion symmetry(notably crystals, certain ceramics, and biological matter such as bone, DNA and various proteins). 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 converse piezoelectric effect is used in production of ultrasonic sound waves.[4]

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 also a vector or a directed quantity. Dipoles near each other tend to be aligned in region called Weiss domains. The domains are usually randomly oriented, but can be aligned during poling (not the same as magnetic poling), a process by which a strong electric field is applied across the material, usually at elevated temperatures 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 the orientation of **P** within the crystal, crystal symmetry and 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 electrical field extending between the faces, since the units of surface charge density and polarization are the same, [C/m2] = [Cm/m3]. In fact, however, piezoelectricity is not caused by a change in charge density on the surface, but by dipole density in the bulk. For example, a 1 cm3 cube of quartz with 2 Kilo Newton (500 lbf) of correctly applied force can produce a voltage of 12,500 V [5].

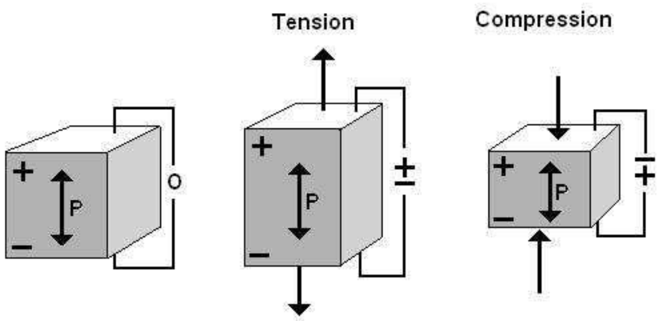

Fig 1. The direct piezoelectric effect

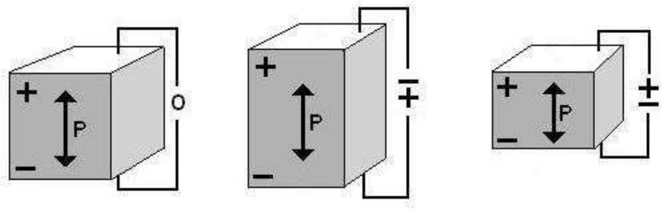

Fig 2. The converse piezoelectric effect

III. APPLICATIONS OF PIEZOELECTRICITY

Currently, industrial and manufacturing is the largest application market for piezoelectric devices, followed by the automotive industry. Strong demand also comes from medical instruments as well as information and telecommunications. The global demand for piezoelectric devices was valued at approximately US$14.8 billion in 2010. The largest material group for piezoelectric devices is piezo crystal, and piezo polymer is experiencing the fastest growth due to its low weight and small size, high voltage and power sources.

Piezoelectricity is found in useful applications such as the production and detection of sound, generation of high voltages, sensors, actuators, frequency standard, piezoelectric motors, reduction of vibrations and noise, electronic frequency generation, microbalances, ultrafine focusing of optical assemblies and piezo-smart roads.

IV. PIEZO-SMART ROADS

The property of piezoelectric materials to produce electricity on compression is employed to harness energy of vehicles moving on roads by making the roads "PIEZO-SMART". This revolutionary new surface uses piezoelectric crystals embedded in the asphalt to generate up to 400 kilowatts of energy from a 1 kilo meter stretch (a design, devised by Haim Abramovich, a developer at the Teknion-Israel Institute of Technology in Haifa, Israel) enough to run eight electric cars. A kilo meter of "Piezo-smart road" could generate enough power for 40 houses, and progress in the technology could generate enough electricity to feed the national power grid. Private companies were competing in this sector but recently governments of developed countries are also taking notice to the developments in turning traffic rush into electricity and are funding many projects.

V. CONCEPT

The energy consumed by the vehicle (sourced in the fuel combustion) utilized for a variety of applications; one of them is to overcome rolling resistance. A typical asphalt road can be described as a visco-elastro-plastic material, with elasticity being its dominant material characteristic. When a vehicle passes over a road, the road deflects vertically. This deflection is released as thermal energy. For a road with embedded piezoelectric generators, part of the energy the vehicle expands on roads deformation is transformed into electric energy (via direct piezoelectric effect) instead of being wasted as thermal energy (heat).

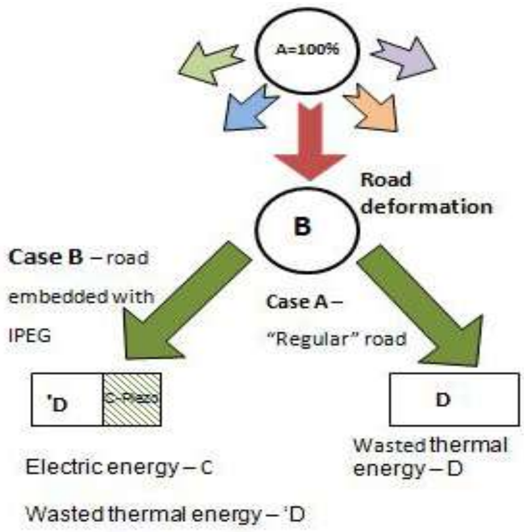

Fig 3. shows a design of Traverse of energy

VI. WORKING

Only part of the energy from the fuel combustion of the vehicle is used for moving the car along the road or run useful accessories, such as air conditioning. The rest of the energy is lost to engine inefficiencies. The energy expended on the vehicle's movement is mainly used to overcome rolling resistance, resistance occurring when the wheel is moving forward on the road surface. In addition to the energy used to move the wheel forward (in the horizontal direction), part of the fuel combustion is wasted on creating a deformation in the asphalt, which is basically the product of the loaded wheel's influence on the road surface. A typical asphalt road can be described as a visco-elastoplastic material, with elasticity being its dominant material characteristic. When a vehicle passes over a road, the road deflects vertically. The deflection is proportional to the weight of the vehicle and the asphalt stiffness. The only source for harvesting electric energy is this part of mechanical energy related to the asphalt vertical deformation, which is a percentage from the total energy of the vehicle (energy of the fuel combustion). It is known that the vertical load of the vehicle's wheels yields compression stress, diminishing with depth. Piezoelectric generators are embedded at a depth of about 5 cm; the area where the compressions stress is maximal. The external load results in the deformation in both the asphalt layer covering the generators and the generators, similar to the typical deformation in a piezoelectric column loaded under axial load. The deformation of the generator and the shortening of the piezoelectric columns embedded in the generators, generate charges on the piezoelectric columns that are the source for the electric energy. The energy needed to deform the road is a function of various parameters such as: the surface quality of the road, asphalt type, environment temperature and others.

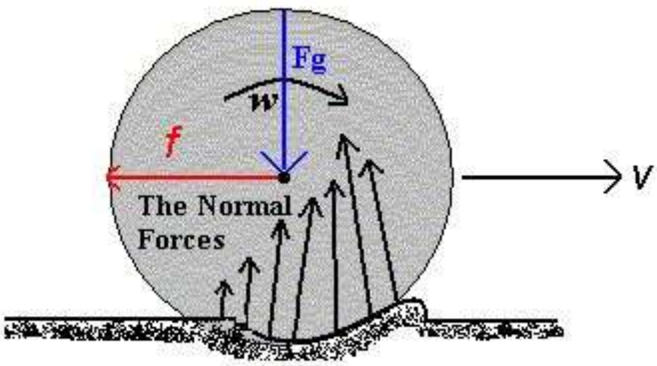

Fig 4. shows Production of electricity from roads

VII. MECHANISM & EFFICIENCY

Now this whole concept is the key to the piezoelectric roads. Those crystals exhibiting the piezoelectric effect are laid 5 cm below the surface of the road. A vehicle passing down a road way and causes deformation of the road. Every time the vehicle moves over the crystal, the piezoelectric crystal is slightly deformed. Generally all the energy wasted on the piezoelectric crystal deformation is transferred into electricity via piezoelectric generator. It converts the mechanical energy of the road deformation into electricity which is either stored in batteries or connected directly into the grid. This

energy harvested can be supplied road lighting, stoplights, speed sensors, road side hoardings etc. From the figure 5, it is seen that the piezoelectric crystals are embedded in the red marked spots. For example when a truck moves, the deformation is produced and the corresponding potential is produced according to the figure 1. This is supplied to the nearby lamps for lighting. It is found that when one vehicle moves for every second, in a road span of 1Km embedded with these piezoelectric crystals, then power of 240.12Kw could be produced. A typical mercury vapor lamp requires around 500W.Hence the energy derived from the piezoelectric crystals will be adequate enough for lighting these lamps on the roadside.
The busier the roadway the more energy is produced. Similarly this concept can be installed in pedestrians, Airports, Railway lines etc. The solution harvests the energy wasted during human movement (e.g. walking, driving).The popular indoor locations for such implementation would be major public transportation stations, e.g. shopping malls, entertainment parks etc.

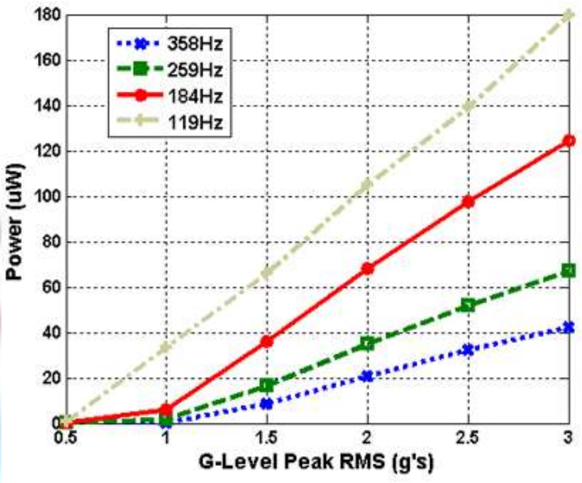

Fig 5. shows the efficiency graph

VIII. DESIGNS

Several designs are being proposed and utilised at different places in the world.

One design consists of a thin box around the piezoelectric material, which is then placed underneath a layer of asphalt. As trucks pass over plates embedded in the asphalt they compress a tank of hydraulic fluid under the road, which in turn creates a series of pumping actions that turns a generator to produce electricity. When a car drives over the box, it takes the vertical force and compresses the piezoelectric material, thereby generating electricity. The energy—80 kilowatt-hours per kilo meter of road for car traffic—can be stored in a nearby battery or super capacitor, depending on the application, or sent directly to streetlights and other roadside devices. The energy being converted into electricity through piezoelectric effect is coming from motion of vehicle which will otherwise be wasted by heat when the road deforms under the weight of the car. The layer of piezoelectric material is stiffer than the road material it replaces, so it even saves a tiny amount of energy.

Another design aims to capture energy when vehicles are slowing down in which cars or trucks would drive over a mat that would be installed on top of the road, on a highway off-ramp, or near a toll booth, saving wear and tear on the car brakes and transforming some of the slowing vehicle’s motion into electricity. The mat uses mechanical or hydraulic cells to generate electricity and can be customized for cars or cargo truck traffic. The idea of skimming kinetic energy from slowing vehicles before it gets wasted as heat has already undergone a few real-world tests, with mixed results. In such a test, the panels produced as much as 40 kilowatt-hours but panel seals suffered damage from grit, temperature extremes, and torsion from trucks turning on them. Efforts are being going on to modify the system considering the problems insurmountable.

Engineers have created a new type of road capable of turning the vibration caused by cars into electricity. While the concept is not new, the application is a novelty. The piezoelectric generators harvest the vibrational energy and save it in roadside batteries that can be used by people. Accordingly, one truck can generate 2,000 volts which could already be used to power traffic lights or street lamps.This process is also known as Parasitic Energy harvesting. Under the upper asphalt there is a layer of piezoelectric crystals that produce electricity when squeezed. The same technology can be implemented on airport runaways and rail systems. The system also has the capacity to deliver real-time data on the weight, frequency and speed of passing vehicles as well as the spacing between vehicles. Future plans include placing the crystal generators in railways. Trains are advantageous in that they are guaranteed to apply pressure in the same place over and over again.

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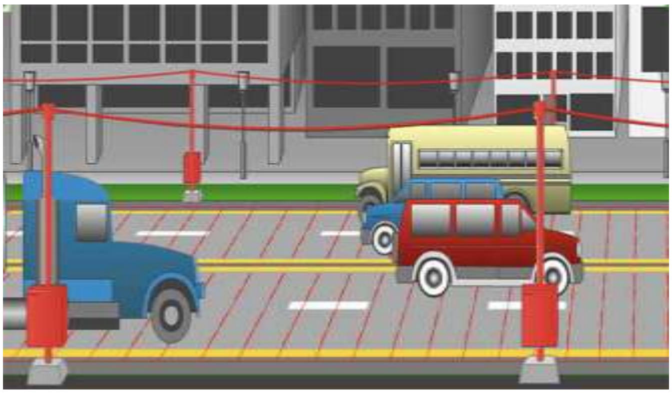

Fig 6. shows the graphical model of the concept

IX. PRACTICAL APPLICATION OF PIEZO SMART ROADS

Here we have listed an energy generating road design that have been proposed in recent tim**e.** The piezoelectric energy-generating roads have been proposed in the car capitol of the world – California.

Fig 7: showing piezoelectric energy-generating roads.

This design is based on the concept of piezoelectricity that is produced in response to the mechanical stress applied on some solid materials like crystals and some ceramics. The design proposes the placement of piezoelectric sensors beneath the road surface which would produce electricity from the vibrations caused by the movement of vehicles on the road. When applied on roads, the piezoelectric technology could produce up to 44 megawatts of electricity per year from one kilometer stretch of the road and meet the energy demand of about 30,800 households.

X. HIGHLIGHTS OF PIEZO-SMART ROADS

A. Advantages

1) Movement of vehicles are always constant on busy roads and highways so, power can be generated constantly by this concept.
2) Power generated from ‘Piezo-smart roads’ concept is Greenpower and no harm to the environment.
3) This power can be very well utilized for the street lightning and other small scale purposes.
4) This source of electrical energy is a long term investment having merits of being a continuous source, independent and unaffected by climatic conditions.

B. Disadvantages

1) Implementing this concept is a little bit tedious.
2) The present day roads need to be relayed again in order to implement this concept.
3) This will result in traffic congestions all over the city and needs a critical plan of implementation and management.

CONCLUSION

At a time when governments are finding it hard to make land available for new power plants, extracting energy while using the vast spread of highways all over the world seems no less lucrative proposition. However, this idea has not yet gained enough ground among the policy makers even though researchers have shown that energy could be extracted from highways by fitting them with piezoelectric devices, solar panels, wind turbines and other energy generating tools.

Future of the world would depend on our ability to create a self-sustaining environment where everything could be put to some use and dependent on each other. The energy generating road designs could become a starting point for a self-sustaining future.

We thus conclude that this thought will be a revolution in power production and curb down the energy costs thereby improving our country's economy. This energy is produced by consumers' participation without requiring any kind of input energy. Further concentration in the work would result in the better production of energy. We can see a better dimension of this piezoelectric concept in the futuristic world.

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