Piezo- Future's power pack

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Abstract

The increasing worldwide energy crunch is forcing us to shift our focus from the scanty natural wealth to much cleaner, cheap and reliable source of energy. The Piezo proves to be a solution. 'Piezo' means pressure. Certain substance like Quartz, Tourmaline, Zinc oxide etc.., when subjected to a mechanical pressure, generates an alternating voltage which can be directly brought under use to charge various electrical appliances. This is a fun way of charge production where in the regular body motion is harnessed for generating electricity. This paper will leave one in a complete awe and wonder. Have you ever wondered the dance moves which you show in clubs, the tedious workouts done in gym, the rush on the train stations, vehicles passing by the road, the messages that we type on phone; all could be harnessed into electricity? This paper gives a detailed application of the piezoelectric phenomena in physical, industrial and biological world, elaborating devices like 'Push to charge cell phones' to use of nano ribbon Piezo implants in the human body. Piezo has a great scope but it is still unrevealed. This paper is an attempt to bring Piezo in the picture as a hope for future's eco-friendly economic source of energy. Piezo can prove to be a revolution in this energy era!

Key words: Piezoelectricity, Nano ribbon implant, piezoelectric transducer, MEMS (Micro electromechanical systems), PZT (Piezoelectric transducer).

1. Introduction

The increasing demands of energy by the human race and the depleting natural resources have made us to think about an alternative source of energy. The stress on coal and hydrocarbon reserves has been reduced to some extent by harnessing the solar, wind, water energy etc…but it's not cheap. As such, search of reliable, eco-friendly and economically affordable source of energy is the need of the hour.

Scavenging energy from the mechanical vibrations found freely in every environment will be sustainable and efficient. This method of producing an inexhaustible energy from the mechanical vibrations is called the piezoelectric effect. The piezoelectric effect is the ability of certain materials to generate AC voltage when subjected to mechanical pressure or vibration which can be used to charge the electrical gadgets and also can be stored in batteries for future use. This method of producing energy from untapped mechanical vibrations is very economical and eco-friendly as well.

2. Concept of Piezoelectricity

"Piezo" in Greek, means "pressure". When any object is pressurized, part of the object compresses while the other expands. As such, once piezoelectric material is pressed by any means, a potential is created by the arrangement of all the negative charges on the expanded side and a positive on the compressed side [1]. As soon as the pressure is released, an electrical current flows across the material. Quartz, Rochelle salt, zinc oxide and certain ceramics exhibit piezoelectric behavior. The most commonly used piezoelectric ceramic is barium titanate. Thus, piezoelectricity is the electric polarization in substances resulting from the application of mechanical pressure.

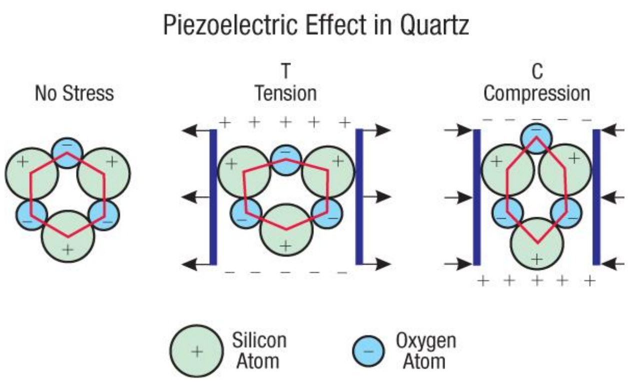

Figure no. 1 – Piezoelectric effect in Quartz crystal.

Piezoelectric materials also show the opposite effect, called converse piezoelectric effect that is when an electric field is applied, mechanical deformation is produced in the crystal. Using this effect, a high-frequency AC current can be converted to an ultrasonic wave of the same frequency, while a mechanical vibration, such as sound, can be converted into a corresponding electrical signal. [4] The piezoelectric effect is particularly useful in converting mechanical strain into electrical impulses and electrical impulses into mechanical strain. In short, Piezo stands as a robust example for mechanical-electrical transformations.

3. Ionic structure of piezoelectric materials

Every substance has a crystal structure having atoms, molecules arranged in a specific pattern, with an endless repetitions of the same basic atomic building block called the 'unit cell'.[2] Most of the solids (like metals) have a very ordered and symmetric arrangement of these repetitive unit cells. Thus they have a very stable conformation.

Piezoelectric materials are unsymmetrical. The arrangement of the positive and the negative ions is unordered. But piezoelectric crystals are electrically neutral. Even though the arrangement of the atoms is haphazard, they maintain a net zero charge. A positive charge in one place cancels out a negative charge nearby. More specifically, the electric dipole moments—vector lines separating opposite charges—exactly cancel one another out.[1-2] However, if these materials are squeezed or stretched, the structure is deformed. This pushes some of the atoms closer together or further apart, disrupting the balance of positives and negatives, and thus forcing the charges out of balance. This effect carries through the whole structure producing a net positive and a net negative charge appear on opposite, outer faces of the crystal thus producing piezoelectricity!

4. History of piezo

Piezo was introduced in early 1880's by Curie brothers- Pierre and Jacques Curie. [3-4-11] In 1881, Lippmann deduced mathematically the converse piezoelectric effect from the fundamental thermodynamic principles. [11] It took around 25 years to identify and define 20 natural crystal classes in which piezoelectric effect occurred.

During the First World War in 1917, P. Langevin and his French co-worker carried out the experiment on Piezo.[3] They developed the first ever Piezo appliance called as the SONAR (Sound Navigation and Ranging System), which achieved their goal of emitting a high frequency "chirp" under water, measuring the depth by timing and return echo. The success of SONAR developed many piezoelectric devices such as Mega cycle Quartz resonators, Acoustic holographs, microphones, accelerometers, ultrasonic transducers, signal filters, phonograph pick-ups, etc. [4-11]

5. Piezo in 21st century

With the rising energy crisis and eco-imbalance across the globe, the time has come to explore the other aspects of Piezo. Continuous fall in the natural resources and protecting the environment, Piezo may prove reliable, eco-friendly, sustainable and economic solution. The frugal mind of the scientists have brought many innovative ideas , where the freely available mechanical and vibrational energy by wind, water, humans, animals, birds, motors on the road, trains, planes, all could be the input leading the output as the electricity! Piezo inculcated devices like as push to charge cell phones, laptops chargers, piezoelectric shoes, piezoelectric floors, Piezo automobile tires etc. All of these were practiced in countries like Japan and Israel. [7, 8]

Piezo may be included in biological world for developing electric current from the involuntary movements of some internal organs like heart, lungs; diaphragm etc…could charge the electrical implants like pacemakers, defibrillators and thus increasing their life. Thus Piezo are stretched from the physical to the biological world altogether.

6. Working principle of piezo

Piezo are one of the most smartly used materials, having a wide band width, relatively fast electro mechanical response, comparatively lower power requirements and varied generative forces. Piezoelectric materials (PZT) can be used as mechanisms to transfer ambient vibrations into electrical energy that can be stored and used to power other devices. With the recent surge of micro scale devices, PZT power generation can provide an alternative to traditional power sources used to operate certain types of sensors/actuators, telemetry, and Micro-Electro -Mechanical Systems (MEMS) devices.[13]

The energy produced by the PZT can be stored in two different ways. The first is in a capacitor and the second method is as a charged battery. Piezoelectric materials form transducers that are able to interchange electrical energy and mechanical motion or force. By implementing power harvesting devices we can develop portable systems that do not depend on traditional methods for providing power such as the battery, which has a limited operating life.

There are basically 3 types of energy harvesting technologies being exploited worldwide; they are –Electromagnetic, Photovoltaic and Thermoelectric. These are among the best harvesters in terms of power density, efficiency, life and cost. The following table compares the power densities and efficiency of these conventional harvesters with piezoelectric energy harvesters and proves piezo as a promising energy harvesting technology for use.

Energy source	Power Density [mW/cm^3]	Efficiency [%]
Photovoltaic*	500-5000	5-40
Piezoelectric	0.001-90	25-60
Electromagnetic	0.1-50	30-40
Thermoelectric*	50-500	0.1-10

Table No. 1- Different forms of energy sources and their power densities and efficiencies. [5]

*= Technologies with no moving parts

This shows that piezoelectric proves to be the most efficient way of storing electricity.

7. About Piezo MEMS[10-12]

Micromechanical electromagnetic systems (MEMS) involve micron-scale mechanical and electrical components with mobile parts. Piezo MEMS are energy harvesters, made of specific dimensions with attached piezoelectric materials which resonate at the target dominant frequency, creating a resonance. The Piezo MEMS sensor or actuators are widely used in industry in electro mechanic, optoelectronic or micro-fluidic systems.

The advantages of piezoelectric energy harvesters are such as highest efficiencies and power outputs by size and cost, high-performance solution, eco-friendly, saving energy etc…

8. Piezoelectric devices

The new innovative way of harnessing the mechanical vibrations into transducers has given us an open package for electricity usage and storage. A few frugal ideas are brought under practice and some could be seen soon in the main stream...

8.1 Push to charge cell phones[14]

Cell phones have become an integral part of our day to day life. The obsession for typing, texting, messaging can be seen spread all over the globe. Although it is a little annoying, but what if each of those taps on the phone’s screen could create electricity! The basic idea is Piezo.

These piezoengineered cell phones would feature plastic buttons layered over a hard metal. Piezoelectric crystals would occupy the bottommost layer. Each time a button is pressed, the hard metal placed underneath would directly hit the basal crystal like a hammer. This would make the piezoelectric crystal to vibrate, thereby producing an electrical potential i.e. voltage. The charge produced will be sent to the battery via small wires present between the layers. This stored energy will be then used to run the cell phone. It's estimated that one tap on this phone's screen could produce a miniscule of 0.5 watt which is very small, but if we multiply it with the numbers of taps done to type messages sent all day, it's quite a lot of wattage. This technology could be used in any system featuring buttons like computer keyboards, remotes, video games etc. Thus electricity will be produced simply by typing on a keyboard or staying in touch with your family and friends!

8.2 Piezo electric automobile tyres[9]

Most of the batteries have a limited range, which reduces the efficiency of the vehicles only to short trips. However, an internal combustion engine is included for recharging the batteries by burning conventional fuels like petrol and diesel. Thus the range is extended range, but this the vehicle run entirely on electrical driveline. Therefore there is a dire need for a cleaner power-generation technology that will allow maximum range extension with minimal environmental consequences. Piezo could be explored here.

Piezoelectric material could utilize the friction produced between the tyre and the road surface to generate electricity. Specially designed piezoceramic benders made of PZT like lead zirconate titanate is attached to pneumatic tyres. These benders are cyclically deformed due to the abrasion of the tyre by the contact patch. The vibration creates potential which is intermittently supplied to the tyre-pressure sensors. Higher power outputs can be obtained by maximum covering of the tyre's inner surface area. Since energy is produced through deformation at the road- tyre interface, it proves to be reliable and continuous energy source for the onboard vehicles.

Figure 2- Inner surface of a tyre with an array of lead zirconate titanate benders

In 2009, an experiment was conducted were a 4×40 array of highly bendable, low-cost PZT elements was bonded to the inner surface of a tyre using a flexible adhesive. To test the power output, rotation per minute (rpm) was measured by applying the output voltage across resistance values [9]

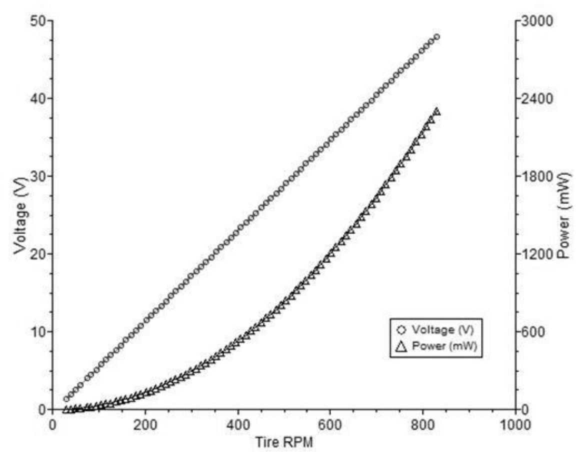

Figure No. 2-Voltage and power across a 1000Ωload at various rotations per minute.

It was found that 4.6 watts was generated with PZT benders which provided sufficient proof of the feasibility of using this method for running onboard devices. Power was extracted from this system showed great results saving most of the expenses done on petrol and diesels.

8.3 Just walk a kilometer and you can charge your smart phones![14]

This is very efficient way of production of electricity by mere walking. The sole of any regular shoes is in co-operated with a Piezo cell which has a small battery on the inner side. When a person walks about one kilometer, he or she can produce enough power to charge batteries of their mobiles, laptops and any other portable gadget. This method is a very easy way where one could generate electricity by his/her footsteps. Such a devised shoe cost just Rs.100/- more than its regular price, making these very affordable. Moreover this will not only solve the energy woes but also improve the health of the people as they will walk more.

8.4 Piezo floors[6-7]

The population rise is the growing concern that has lead to this worldwide energy crisis. But what if we could reap the benefit from this exponentially risen people all around? Piezo shows another hope here. When a foot hits the floor it creates a pressure. When the flooring is piezo-engineered these vibrations are captured by floor sensors and are converted into electrical charge by the piezoelectric crystals. This energy can be then stored or used as a power source. With the installation of the ceramic layers in the floorings at rush places like train stations, bus stations, concerts, malls, multiplexes, were large groups of people move, a lot of lost energy can be trapped.

8.5 Piezo dance floors[6-7]

In some of the famous clubs around the world an experiment was conducted in 2007, the floors of the clubs were Piezo-engineered. The vibrations created by the movement of the dancing clubbers were trapped on energy-capturing floors. The electricity thus generated was supplied to power LED lights and music systems of the club. Initial estimates suggested that an individual clubber could generate roughly 5 to 10 watts, however when the dance floor was highly completely packed, the energy produced contributed more than 50% of the club's total energy needs, enough to save us from this energy crisis!

A similar experiment was conducted in Japan in 2008, by the East Japan Railway Company (JR East). Piezoelectric pads were installed in the flooring of the ticket gates at a station in Tokyo. Electricity produced was used to power lighting and automatic gates on the station.

8.6 Piezo engineered train-tracks[8]

Recently, a new use of this versatile energy was unveiled by an Israeli company Innowattech. They installed piezoelectric pads on the rail track. A test was conducted on this railway track by trafficking some ten-car trains on it. It was found that around 120kWh could be produced; this energy was enough to power infrastructural systems like signals and lights. Also any surplus energy could be uploaded to the nation's power grid. This proved to be another success in Piezo engineering.

Figure No. 3- Piezo-engineered railway tracks.

9. Piezo and biology

With the varied applications of Piezo in the physical world, scientists are looking forward for including Piezo in the biological world too. And here is the application.

9.1 Nano-ribbon Piezo implants in the human body [11]

Biomedical devices like pacemakers, heart rate monitors, cardioverter-defibrillators, neural simulators and many more solely depend on a battery for their functioning. Researchers from the world-wide institutions and universities are working together to develop a piezoelectric device that when implanted into the body, could generate electricity to run any implantable biomedical device.

This can be achieved by implanting nano-ribbons made up of piezoelectric materials connected to organs that have an involuntary motion like heart, lungs, and diaphragm. This method will be capable of producing, harvesting and storing energy from these natural contractile and relaxation motions at levels that fulfills all the requirements of the devices. This way of harvesting power from the natural body process seems to be an attractive alternative for these biomedical devices.

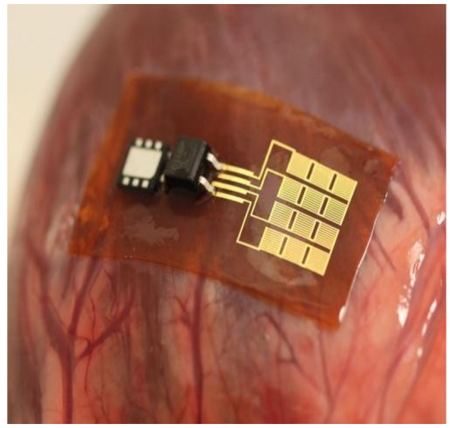

Figure 4- The nano-ribbon Piezo implant on the heart.

A miniature of this Piezo cell was built using lead zirconate titanate in the form of nano-ribbons with an attached mini rectified rechargeable battery covered by a flexible, biocompatible plastic. This device was directly sewn onto the heart, lungs or diaphragm. Their movements slightly bended the ribbons, which in turn created a small amount of electricity. This electricity is directly fed to the devices like pacemakers. This method can stretch the lifeline of these implanted devices from 5-6 years to lifelong thus preventing the expenses done in reoperation and new installation of these devices into the body.

10. Conclusion

Piezoelectric science was understood in the 19th century but its applications were never explored. On an average, an active human consumes around 3,000watt/hour of energy per day.[ ] This seems to be a large amount however 3 times of this energy can be produced by simple bodily actions like walking, sprinting, running and all. What if this wattage could be turned into usable energy?

Piezo explores the power of the people!

Thus Piezo stands as a great hope for the epidemically rising energy and environmental woes worldwide.

11. Future of Piezo

In spite of the successful production of a variety of piezoelectric devices, the true origin of the piezoelectric effect is often obscure and the devices not necessarily optimized. Lot of work is yet to be done. Use of piezoelectric crystals has being started and positive results are obtained. With further advancement in field of Electronics, better synthesized piezoelectric crystals and better selection of place of installations, more electricity can be generated and it can be viewed as a next promising source of generating electricity.

12. Acknowledgement

Images and information are sourced from www.google.co.in.

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