Piezoelectric Energy Harvesting using Vibration Energy from Shoe Sole: A Review

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ABSTRACT

It has been understood & realized by studying various research papers that the area of energy harvesting from environment is the topic of research. Since in the last few years, the demand of electrical power is increased rapidly due to advancement of technology in comparison to the power generated so researchers have turned towards research in the area of energy harvesting from the surrounding environment. The MEMS technology and low power (LP) operated electronics devices have opened the doors for power harvesting systems in practical real world applications. In Energy harvesting technique the mechanical vibration energy is sensed by a sensor which converts vibration energy into useable electrical energy. For achieving the title of our paper here we are using piezoelectric crystal which is converting mechanical vibrations into an electrical energy .The conversion of harvested energy is very good in scalability, capability and high energy density and compatible with standard electronic technology[3].

A piezoelectric power harvesting system has two sections: a transducer (piezoelectric crystal) which converts the mechanical vibration to irregular AC voltage, and an electrical interface, which converts the irregular AC voltage to DC voltage called as rectifier. Rechargeable battery has been used to store the rectified energy. Low power (LP) electronics devices are battery powered, so these devices are powered by power harvesters also called as energy harvesters. Walking is daily life activity of a person which provides the solution to charge the low power (LP) electronics devices by using piezoelectric harvester through shoe sole.

On the basis of reviewed references of the researchers we have prepared a comparative tables for various parameters which gives the brief description in the area of piezoelectric power harvesting and the future goals that must be achieved for power harvesting systems.

Keywords: EGS, LP, PH, WS.

Introduction

The process of capturing the wasted energy from the environment is called power harvesting. The sources of energy are solar power, thermal energy, wind energy and vibration or mechanical energy. From all the sources of energy mechanical vibration energy is of great interest for the researchers. Mechanical vibration is readily available in the environment and is easily converted in usable electrical energy by using piezoelectric element as power harvester for powering low power (LP) electronics devices.

As piezoelectric power harvesting that has been receiving the most research so in our paper we reviewed and detailed some of the topics including energy harvesting from mechanical vibration.

Principles and Structure of Piezoelectric Effect

The word Piezoelectric is derived from the Greek piezein, which means to press, and *Piezo* which is Greek for "push".

The **piezoelectric effect** was discovered by Jacques and Pierre Curie in 1880. They found that if certain crystals were subjected to mechanical strain, they became electrically polarized and the degree of polarization was proportional to the applied strain (the material acts as a sensor).

The inverse piezoelectric effect was also discovered Jacques and Pierre Curie in 1881. They found that that the same materials deformed when they were exposed to an electric field applying voltage (the material acts as an actuator).

The phenomenon of direct piezoelectric effect (DPE) is shown in Fig.1 and Fig.2 [8]

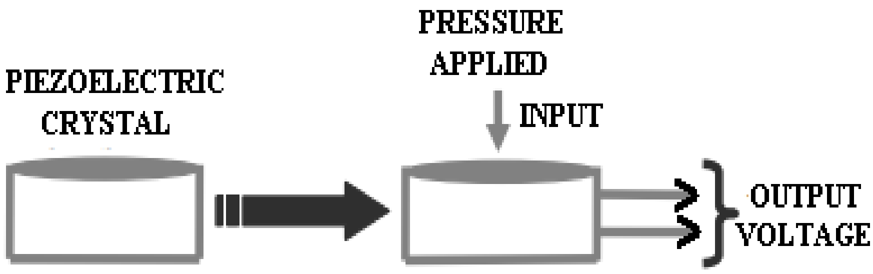

Fig. 1 Principle of direct piezoelectric effect

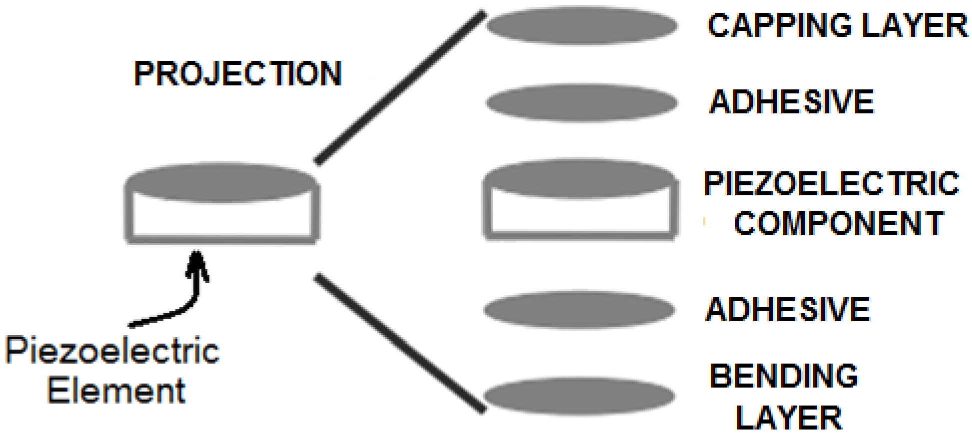

Fig. 2 Structure of piezoelectric element

According to Hooke's Law:

$$S = s\,T \qquad (1)$$

Where S is mechanical strain, s is opposite of strain and T is stress.

As piezoelectricity is related to electrical and mechanical properties, the volumetric charge density can be calculated by considering the electric field and permittivity:

$$D = \varepsilon\,E \qquad (2)$$

Where D is volumetric charge density, ε is permittivity, and E is electric field.

Due to piezoelectric effect these materials are able to convert mechanical ambient energy (vibration) into electrical energy.

Coupling Modes of Piezoelectric Material

Piezoelectric material has two coupling modes for their proper operation. These two modes of operation are particularly important when defining the electromechanical coupling coefficient. First mode is called as -31 modes in which a force is applied in the direction perpendicular to the poling direction, an example of which is a bending beam that is poled on its top and bottom surfaces. And the second is called as -33 modes, in which the, a force is applied in the same direction as the poling direction, such as the compression of a piezoelectric block that is poled on its top and bottom surfaces. The 31 and 33 mode is shown in Fig. 3.

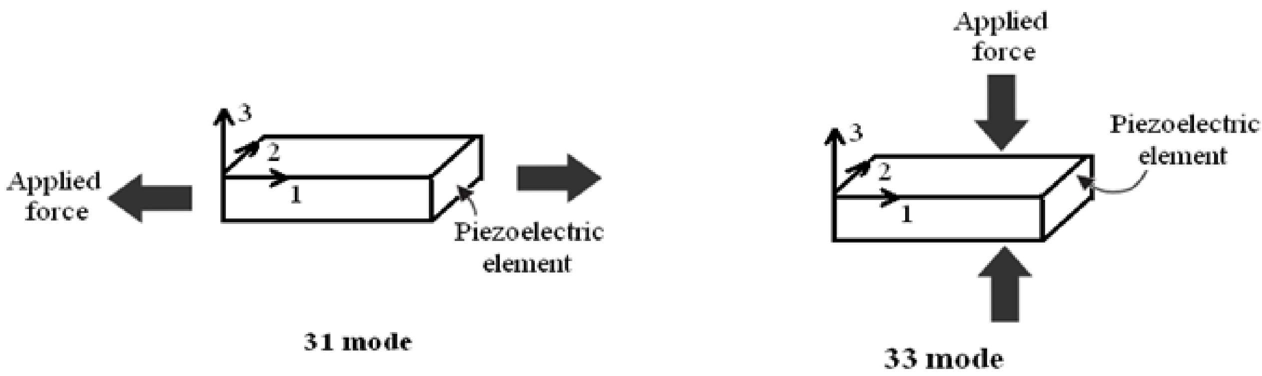

Fig. 3 Piezoelectric coupling modes

Piezoelectric Material used for Energy Harvesting

The properties of piezoelectric material belong to a larger class of ferroelectrics in which molecules are oriented in such a way that the material exhibits a local charge separation, known as an electric dipole. The electric dipoles are orientated randomly throughout the material composition, but when the material is heated above a certain point, the Curie temperature, and a very strong electric field is applied, the electric dipoles reorient themselves relative to the electric field; this process is termed poling. Once the material is cooled, the dipoles maintain their orientation and the material is then said to be poled. After this process the material will exhibit the piezoelectric effect. Most common type of piezoelectric material used in power harvesting applications is lead zirconate titanate, piezoelectric ceramic, or Piezo ceramic also known as PZT.PZT is widely used power harvesting material. While applying pressure or force on piezoelectric element it converts pressure into separation of charges with in piezoelectric element which results in generation of potential difference in form of electrical energy.Fig.4 shows the schematic diagram of generation of electric signal while applying pressure.

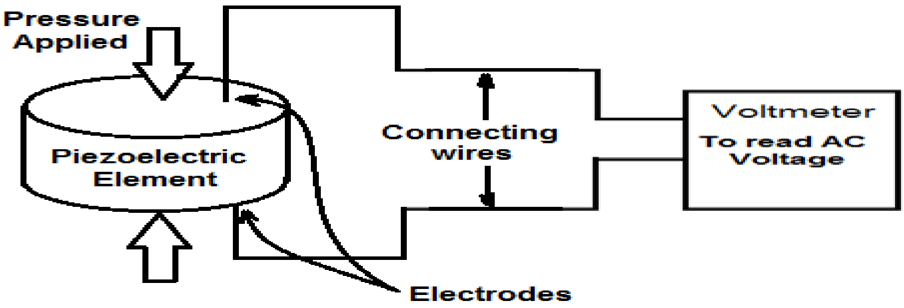

Fig. 4 Generation of Electric Signal while applying pressure

Table I shows the comparative review of some introductory parameters.

Table I

S.N.	Parameter	Ref 1	Ref 2	Ref 3	Ref 4	Ref 5
1	Material	Piezoelectric	Piezo ceramic composite, rotary magnetic generator and multilayer PVDF foil	piezoelectric transducer	Piezo ceramic bar magnet moving in translation through a coil	PZT, Quick Pack, macro-fiber composite
2	Properties	Piezoelectric materials create electrical charge when mechanically stressed.	Rotary magnetic generator capable of very high conversion efficiency	thin plate element has a mechanical advantage in converting applied pressure to working stress for piezoelectric conversion	thin plate element	Vibration produced by vibrator
3	Effective Mode of operation	33 mode	31 mode	33 and 31 modes	33 mode	33 mode

Literature Review

We have studied the utilization of piezoelectric material for energy generation from shoe sole by various research papers of different authors enlisted as a references in my paper. It has been tabulated in table no. 2 calculated that up to 67 Watts of power are available from heel strikes during a brisk walk (68 kg person, 2 steps/sec, heel moving 5 cm).This level of power extraction from walking would certainly interfere greatly with one's gait. But there is much less energy of this type than available through deliberate means of harvesting human power [1]. A piezoelectric system was developed that harvest the energy during walking and used it to power a radio transmitter. A capacitor is used to store rectified energy with an electronic switch which decides the charging and discharging level. It was found that the two piezoelectric devices used can produce sufficient energy to power a transmitter that could send 12-bit radio frequency identification (RFID) code every 3-6 step. The investigation that power harvested could supply sufficient energy to power a transmitter opened doors for research into wireless sensors [2].In the continuation of research it was investigated that energy can be harvested from the motion of humans and animals. They used a thin square plate driven by blood pressure to provide power and was shown to be capable of powering the electronics [3]. The ability of both piezoelectric and electromagnetic power harvesting methods was compared to harvest power from human movement to power portable electronic devices. The electromagnetic system studied was composed of a magnet moving in translation through a coil. The piezoelectric system was made up of a Piezo ceramic bar embedded at one end and free at the other. After an analytical comparison of both systems it was concluded that a piezoelectric system is better suited for micro-scale applications, and electromagnetic system is better suited for macro-scale applications [4].Piezoelectric materials are found in various types so it was investigated and experimentally tested three types of piezoelectric devices to determine each of their abilities to transform ambient vibration into electrical energy and their capability to recharge a discharged battery. He used the monolithic (PZT), the bimorph Quick Pack (QP) actuator, and the macro-fiber composite (MFC). However, the PZT was shown to be more effective in the random vibration environment [5]. One of the researchers demonstrates that the power output from any generator depends on the system coupling coefficient, the quality factor of the device, magnitude and frequency of the input vibrations [6].It was also found that bandwidth, sensitivity and power generation of a piezoelectric element are the key factors in designing a self-powered piezoelectric sensor [7].Table no. 2 shows the comparative review of some introductory parameters which are involved for generation of mechanical vibration through the human body, mechanical devices and materials .

Table II shows the comparative review of some introductory parameters.

Table II

S.N.	Parameter	Ref 1	Ref 2	Ref 3	Ref 4	Ref 5
1	Power generation source	body heat and breath to finger and upper limb motion	Uni morph strip, stave and rotary magnetic generator	Human body	electromagnetic system and piezoelectric bar	PZT,MFC and QP mounted on cantilever configuration
2	Vibration Structure used	Shoe Sole	Shoe sole	square thin plate driven by blood pressure, there existed a strong	piezoelectric long bar, of cylindrical or parallel shape, is embedded	cantilever configuration

				mechanical advantage in converting applied pressure to working stress	at one end and other free end vibrates	

Result

Here we have made a comparative result table by reviewing various reference papers on the basis of various parameters that will be part of energy harvesting by seeing that comparative table we are able to decide which methodology will prefer for generation of harvested energy according to the requirement of researcher. Now, Table III shows the comparative results of a review on Piezoelectric Energy harvesting using vibration from shoe sole.

Table III

S.N.	Parameter	Ref 1	Ref 2	Ref 3	Ref 4	Ref 5
1	Energy lost in environment	67 W	N/A	N/A	N/A	N/A
2	Steps to develop power	2 steps/sec	3-6 steps	N/A	N/A	N/A
3	Weight	68-kg	N/A	N/A	N/A	N/A
4	Activity	Walking	Walking	a fluctuating blood pressure	N/A	N/A
5	Output power	1.5 W	PVDF stave- 20 mW PZT unimorph- 80 mW rotary generator- 1W	Few µW	Piezoelectric material at resistive load of 50kΩ 7.7×10^{-3} mW	N/A
6	Conversion Efficiency	12.5%	N/A	N/A	52%	3.927% for PZT
7	Methods	piezoelectric and rotary generator	Piezoelectric shoe insert	piezoelectric element in two modes	piezoelectric and electromagnetic	PZT,MFC and QP
8	Power storage device	Capacitor: low-power areas such as blood pressure and body heat	Capacitor	Capacitor	Capacitor	batteries

		and rechargeable batteries: for higher power areas, such as limb motion and walking				
9	Advantage	A surprising amount of power (5–8 W) may be recovered while walking at a brisk pace	Both the PVDF stave and PZT unimorphs were easily integrated into a standard jogging sneaker	very low-pressure sources, the 31-mode had a greater advantage in energy conversion	Coupling losses are less for piezoelectric element	Piezoelectric materials form a convenient method
10	Disadvantage	PZT is brittle so it has not have much range of motion in 31 mode direction	rotary generator was not easily integrated into the shoe and significantly interfered with the user's gait	converting applied pressure to working stress for piezoelectric conversion	Magnetic losses are considered	Macro-fiber composite was not well suited for power harvesting
11	Application	CPU	radio transmitter	MEMS	piezoelectric system : micro-scale application and electromagnetic system :macro-scale application	Batteries
12	Data acquisition requirement	N/A	N/A	N/A	N/A	PZT, Rectifier , capacitor and

						battery
13	Transducer used	N/A	2 PE Transducer	N/A	N/A	MFC and PZT both
14	Location of PE transducer	inside the sole of a shoe	inside the sole of a shoe	On human body	inside the sole of a shoe	On vibrating machine
15	Conversion style	high impact vertical energy of the heel to be translated	high impact vertical energy of the heel to be translated into bending strain	N/A	high impact vertical energy of the heel to be translated	Vibrating machine

Future Scope

For the successful use of piezoelectric materials as power harvesting devices system functions in this area are a necessary. The location of piezoelectric materials being placed in the shoe sole defines the conversion efficiency for maximum transfer of pressure applied to the piezoelectric element to get maximum electrical conversion for the power harvester. The structure of shoe sole must be designed such that it provides maximum excitation to the piezoelectric material from the harvesting medium. Finally, practical applications for power harvesting systems like wireless sensors (WS) must be clearly identified to encourage growth in this area of research. The improvement of energy generation and storage (EGS) methods combined with the decreasing power requirements of today's electronics help bring the concept of creating self-powered electronics closer to reality. Therefore, methods of improving the efficiency of piezoelectric power harvesting devices through physical and geometrical configuration are the key technologies that will allow low power (LP) harvesting which becomes a source of power for portable electronics and wireless sensors (WS).

Conclusion

Piezoelectric energy harvesting technologies from vibration using shoe sole were reviewed in our paper. Principle of piezoelectric energy harvesting, vibration structures for piezoelectric harvesting devices and piezoelectric materials were reviewed and investigated. Ambient vibration present in the environment is used as energy harvesting technology which is highlighted as a permanent power source for portable electronic devices and wireless sensor (WS) network. There have been many novel ideas for vibration-based piezoelectric energy harvesters which are matured in conjunction with design technology. However, real applications of the vibration-based energy harvesters are still limited. Energy harvesting by using shoe sole has the limited scope due to various issues. The coupling coefficient of piezoelectric materials is low which affects the performance and is required to be increased. Once the coupling coefficient is increased then the energy conversion efficiency can be improved. The transduction element cannot withstand under critical pressure applied during walking. Thus, development of flexible and resilient piezoelectric materials is necessary. The conversion efficiency of electronic circuitry from pressure applied through shoe sole is low, so the rectification process is to be improved and energy storing elements should be able to activate in such a low power (LP) condition. From the above study it is clear that for energy harvesting from shoe sole the best suited piezoelectric material is PZT, because it has the capability to withstand on irregular vibrations and have the ability to provide high voltages as compared to other power harvesters and flexible piezoelectric materials. Table IV shows the comparative results based on conclusion made on Piezoelectric Energy harvesting using vibration from shoe sole.

Table IV

S.N.	Parameter	Ref 1	Ref 2	Ref 3	Ref 4	Ref 5
1	Conclusion	Walking has the most potential for energy conversion	Magnetic rotary generator produces 2 orders of magnitude more power than Piezoelectric systems, but difficult to integrate with footwear. Both the PVDF stave and PZT unimorph were easily integrated into footwear.	In vivo piezoelectric generator on a size scale of 1cm ^{2}may be able to power a MEMS application in the (mu) W power range continuously and up to the µW range intermittently.	the piezoelectric and magnetic systems are obviously in complete duality in every respect: voltage, current, force and displacement levels, output impedance, resonance frequency and adapted load that maximises delivered Electrical power.	PZT was shown to be more effective in the random vibration

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