Conversion of Electrical Energy from Mechanical Energy WhileWalking Using Special Foot Wear

B B Rath[1],Bighnesh Sahu[2],Chandrabhanu Malla[3]

[1,2]Assistant Professor, Department of Mechanical Engineering, Gandhi Institute For Technology (GIFT),
Bhubaneswar
[3] Assistant Professor, Department of Mechanical Engineering, Gandhi Engineering College, Bhubaneswar

ABSTRACT

In the last few years, there has been an increasing demand for low-power and portable-energy sources due to the development and mass consumption of portable electronic devices. Furthermore, the portable-energy sources must be associated with environmental issues and imposed regulations. These demands support research in the areas of portable-energy generation methods. In this scope, piezoelectric materials become a strong candidate for energy generation and storage in future applications. This paper describes the use of piezoelectric polymers in order to harvest energy from people walking and the fabrication of a shoe capable of generating and accumulating the energy. In this scope, electroactive β- polyvinylidene fluoride used as energy harvesting element was introduced into a bicolor sole prepared by injection, together with the electronics needed to increase energy transfer and storage efficiency. An electrostatic generator was also included in order to increase energyharvesting.

I. INTRODUCTION

As low-power and wearable electronic devices are more and more present in our everyday life, there is a growing need for the delivery of power to different points of the human body. Table I shows the approximate energy consumption for 1 h of operation of some portable devices that can be considered as possible applications of the energy generated by oursystem.

TABLE I Approximated energy consumption for 1 h of operation of some portable devices

Device	Energy
Heart rate meter	3 J
Respiratory rate meter	3 J
MP3 Player	350 J
Mobile phone (conversation)	2800 J
Mobile phone (standby)	150 J

TABLE II Comparison between portable-energy and powersources

The objective of this paper is to harvest energy from piezoelectric materials. The piezoelectric material fabricated inside the shoe which is capable of generating and accumulating energy when peoplewalk.

This project provides solution for converting human mechanical energy into electrical energy. We believe that our approach has the potential to solve these problems for a class of wearable devices by placing both the generator and powered electronics in a location where considerable energy is easily available, namely theshoe.

II. MOTIVATION

Vibration based generators are of three types. Theyare
A. Electromagneticgenerators
B. Electrostaticgenerators
C. Piezoelectricgenerator

Vibration based generators works on the principle of converting mechanical energy to the electrical energy. To achieve the required movement, the generators are coupled with the seismic mass. The suspension and the damping are connected to the seismic mass to give the mechanical support from the outsideworld.
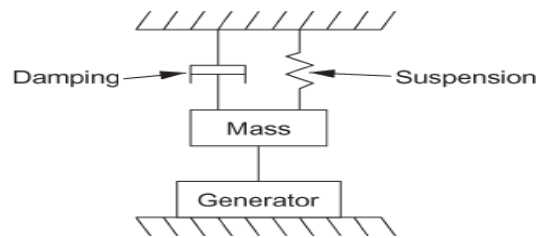
Fig. 1 Schematic diagram of a vibrationscavenger

Fig.1 gives the schematic diagram of the vibration based generatordevice.
The table II specifies the comparison between the vibration based devices and the portable energydevices.

A.   Electromagneticgenerators
In electromagnetic generator works on the principle that an electromotive force (emf) is induced across a coil if the magnetic flux coupled to the inductor changes as a function of time. The relationship between this emf and the displacement of the mass depends on the design of the system. An expression that relates the emf with the displacement (z) can be writtenas,
Emf =k (dz/dt) where k is aconstant.
k depends upon the number of turns of the coil, their length, area, and shape, and the magnetic field intensity. A similar relationship exists between the mechanical force on the coil and the current throughit
F=Ki where K is aconstant.
B.   Electrostaticgenerators
An electrostatic generator consists of a capacitor whose value changes as a function of thedisplacement.
I= [Vo (dc (z)/dt)) +(C (z)(dV/dt))]
Where, V represents the voltage across the charged capacitor, Vo represents the initial value. Vo(dc(z)/dt) represents the value of electromechanical coupling. C (z) (dV/dt) represents the value of the capacitor with respect to the change in voltage and thetime.
The electromechanical coupling attains its value when the capacitor is given the voltage of Vo. The capacitor can be charged either by preloading the capacitor or by using the piezo electric materials which is one of the innovative ideas of ourpaper.
C.   Piezo electricgenerators
The material is said to be piezoelectric when it can perform the conversion of mechanical energy to the electrical energy and vice versa.
The piezoelectric signals are of two types.Theyare
a.   Direct piezoelectriceffect.
b.   Converseeffect.

III. SYSTEM DESCRIPTION
        The idea to use footwear to produce energy has been followed for a long time. In the following sections, the basics in piezoelectric polymers will be discussed, and their suitability for harvesting energy will be demonstrated through the construction and test of a sole prototype. This paper shows an integrated way to include the piezoelectric material into a sole, its geometry and harvesting of the energy. In the next sections, the different steps: development and preparation of the electro active material, positioning of the material into the sole of the shoe, readout electronics design, and preliminary test results of the system will be presented.

A.   Polymerpreparation
        The piezoelectric films can be used for the energy generation. These films are constructed by a polymeric material coated in both sides by conducting material which forms the electrode. The polymeric material is based on the polyvinylidene fluoride (PVDF) polymer in its electroactive (β) phase. It can be processed in the form of a film by extrusion and injection, usually in the non- electroactive α phase. To obtain electroactive β phase, films must be subjected with mechanical stretching at temperature below 100 °C and with stretching ratio 4 to 7. (i.e., ratio between final and initial lengths of the sample) This β phase must be activated by polling. This can be done by subjecting the film to an electric field with amplitude larger than 60 MV/m along the thickness direction. We are going for polymeric films instead of piezo ceramics or single crystals because polymer films are more flexible and can be fabricated in the desired shapes through simple processing process. Also these polymer films are cheap compared to piezoceramics. The electro mechanical properties of film can be improved by treatment that consists of pressing, stretching and polling at veryhightemperatures. The final thickness of the film is in the range of ~ 20 to 60μm.

B.   Positioning of the PiezoelectricMaterial

As piezoelectricity is a dynamic process, the material should be positioned in places were larger and more variable pressure is exerted during walking. Those places are shown in Fig. 2, together with the first prototype. In this prototype, single layers of electroactive material were placed on the top of thesole.

Fig. 2 First prototype of the energy generator.Two piezoelectric polymer films above thesole.

C.   PerformanceTests

The material reacts to pressure variations as it is a dynamic process. The generated voltage changes when the pressure on the material increases or decreases. Fig. 4 shows the experimental setup developed for testing the material performance. A shaker applies force to the piezoelectric material at different frequencies and forces. The voltage is recorded on the digital oscilloscope, and the energy is stored in abattery.

Fig. 3. Experimental setup for materialtesting.
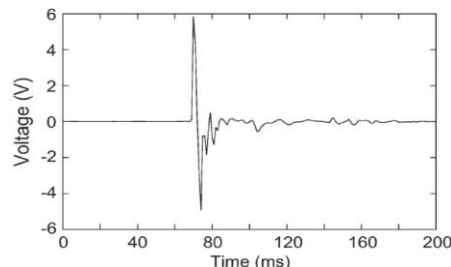

Fig. 4. Voltage change for a single impact applied to thesample.

After the placement of the piezoelectric films into the soles, preliminary tests are performed by simple jumps. Fig. 4 shows the voltage change when a single jump is applied to a 28-μmthick PVDF sample.

D.   ElectronicCircuit

In order to maximize the energy transfer to battery, a rectifying circuit is necessary in order to obtain a single polarity voltage. This circuit consists of a rectifier bridge with four schottky barriers diodes. (These diodes have a forward bias voltage drop near 0.33V.)

The circuit board of the full wave rectifier is then connected to the piezoelectric element placed in the sole and implemented into a shoe (Fig. 5) and further tests are performed in real walking situations (Fig. 6) for test purpose. This circuit can be further more minimized in order to fully integrate it in theshoe.

Fig. 7 shows a photograph of the final circuit. As can be seen, its dimensions are less than a 1-cent Eurocoin.

E.Addition of an ElectrostaticGenerator

In order to increase the power generation, an electrostatic generator was also coupled to the sole. It consist two metallic plates separated by a flexible dielectric material (foam). When a pressure is applied it changes its thickness, i.e., when the person puts his/her foot on the floor. The steady-state capacitance of this electrostatic generator is 20 pF. When the person steps with a foot on the floor, the capacitance increases about two times, this means that the voltage decreases to one-half. At this time, the piezoelectric voltage is higher than the one at the electrostatic generator terminals; therefore, its capacitance will be charged.

When the person presses the shoe, the capacitance of the electrostatic generator decreases and the voltage

increases. In this case, the load is an energy storage device (battery of 3 V); therefore, when the voltage of the electrostatic generator exceeds that of the battery, the charge of the first is transferred to the second. Fig. 8 shows the schematic diagram of the electrical connections between the piezoelectric element, the electrostatic generator, and theload.

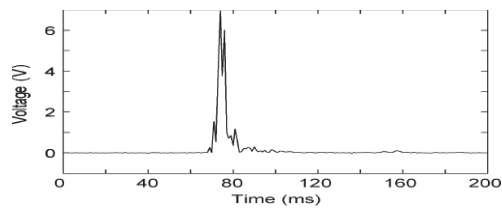**Fig. 5.** Sole and electronic circuit placed in theshoe.

Fig. 6. Voltage versus time after rectification for a single impact applied to thegenerator.

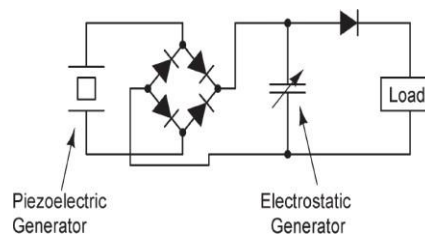**Fig. 7.** Circuit implemented in the final prototype shown on a 1-cent Eurocoin.

Fig. 8. Schematic diagram of the connections between the piezoelectric film and the electrostaticgenerators.
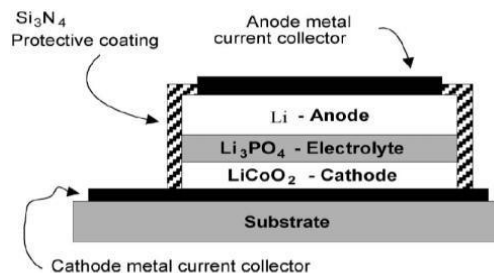

Fig. 9. Cross section of a thin-film lithiumbattery.

E.   EnergyStorage

A thin-film rechargeable lithium battery (Fig. 9) can be used to store the energy generated. All-solid-state lithium batteries, fabricated entirely of thin-film components, achieve capacities over 35 μA · h/cm2, with current densities above 200 μA/cm2, in less than 10 μm ofthickness.

IV. EXPERIMENTAL RESULT

Fig. 10 Performance test. A handspike system was used in order to apply constant pressure impulses to thesole.

Fig. 10 shows the system introduced in a bicolor sole of a shoe prepared by injection molding. It is important to notice that, during this process, temperatures higher than 160 ∘C are reached at certain points of the sole. The power generated by the PVDF foil within the shoes ranges from tens to hundreds of mill watts, depending on the area, the placement, the geometry, and the numbers of foils. It is particularly important that the system allows stretching and not just pressing of the foil, as the longitudinal electromechanical coupling of PVDF (k31) is more efficient that the k33 mode. In this way, the PVDF foils are more efficient in the electromechanical conversion when they are introduced within the sole in the form of a bimorph. A bimorph converts the foot pressure toward the bottom into a combination of pressing and stretching of the PVDF films, making use, in this way, of the k33 and k31 electromechanical conversion. Important for the generation of energy is also the number of polymer layers in each piezoelectricelement.
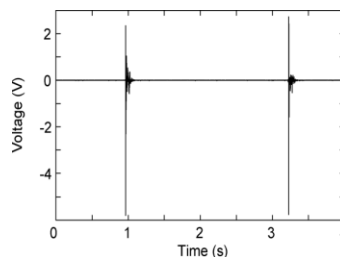

Fig. 11 Voltage generated by a personwalking

Fig. 12 Voltage generated by a person walking with and without the electrostaticgenerator.

The fig. 11 shows the voltage generated by a person walking. The voltage generated in a system with two superimposed layers of piezoelectric material was also tested. The generated voltage was approximately double that of the one generated by the single-layer system. The Fig. 12 shows the whole (piezoelectric + electrostatic) performance. It is possible to see that the output peek voltage value is greater in the case that uses the electrostatic generator. Moreover, its time response is slower, which means that the associated piezoelectric-electrostatic generator supplies energy to the load during a long timeinterval.
We have introduced an idea that the energy generation could be improved by increasing the thickness of the piezoelectric polymer film or by placing four or six generators in each sole or by using films with increased properties with respect to piezoelectricity and elasticity.

V. CONCLUSION

From the several methods available to integrate energy generating elements harvesting human energy, piezoelectric materials associated with electrostatic generators seem to be one of the most promising elements. In particular, electroactive polymers are particularly used due to their low cost, flexibility, and easy integration into shoes. In this paper, electroactive polymers based on β-PVDF have been used in order to fabricate an energy-harvesting system fully integrated into the sole of a shoe. Through the simple configuration and electronics, energy harvesting ispossible.

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