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Piezoelectric Energy Harvesting via Shoe Sole

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***Abstract*— This paper present the experimental design of an energy harvesting system using active materials for power generation from the shoe sole. The active material as PZT has been employed and modified to be appropriately embedded in the shoe sole. When the mechanical pressure is applied to the embedded shoe sole while walking would extract mechanical vibration energy and convert extracted energy to electrical energy directly from the piezoelectric structure inserted in shoe sole via a rectifier to a power processing system. The power processing system regulates the harvested electrical energy and accumulates the generated electrical energy to sufficient voltage level for powering portable electronic devices for later use. In this paper we show the simulation and experimental results of energy harvesting circuit and efficiency of the extracted ambient vibration energy by PZT in terms of electrical voltages during single step and continuous walking for a period of time.**

***Index Terms*— Ambient vibration energy, Energy Harvesting, PZT, shoe sole, power processing system, portable electronic devices and Tina software.**

I. Introduction

Energy harvesting transforms green energy sources into usable electrical energy like solar energy, thermal energy, wind and vibration energy, etc. In the recent years micro power electronics and portable storage devices requires low power requirements for their operations and due to the existing characteristics of such devices the demand for energy harvesting from the surrounding environment increases drastically, due to the low power generation of these energy harvesters [1]. This technology is very attractive for low power portable electronic devices which include pacemakers, flashing LEDs at night, mobile phones and hearing aid devices [2, 3]. One of the most interesting sources for energy harvesting is surrounding environmental ambient vibrations. The sources used for energy harvesting are piezoelectric, electromagnetic, electrostatic, pyroelectric, photovoltaic and thermoelectric. For low power generation piezoelectric source is the best candidate for extracting energy from ambient vibrations. Another reason for using piezoelectric materials is its property to extract energy from ambient vibrations which are readily available from human walking. Piezoelectric energy harvesting is getting more attention due to the fact that it can provide the emergency source for powering low power portable electronic devices in the hilly areas, public places where rechargeable batteries cannot be powered.

This wasted energy is captured by some means and that is called as energy harvesting. During the human motion there is the movement of various parts of the body generates vibrations and these vibration energy can be extracted easily by piezoelectric element into usable electrical energy [4]. The use of piezoelectric materials is feasible since they are much flexible and they can be used with minimal design changes in most of the applications. Heart rate meter and respiratory rate meter have approximately 3 J of energy consumption for one hour of operation. Ambient vibrations consist of a travelling wave on a solid material and it is often not possible to find a relative movement within the reach of a small energy harvester. The piezoelectric materials are attached to the locations where sensible mechanical vibration has to be coupled to the harvester by means of the inertia of a seismic mass. Fig. 1 shows a seismic mass connected to an energy harvester. The mass is also connected to the outside world by means of a suspension/damper system [5].

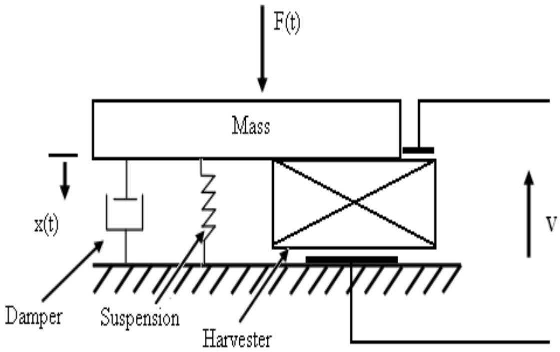

Fig.1 Equivalent model of a vibrating piezoelectric structure

FUNDAMENTAL OF PIEZOELECTRIC MATERIAL

The piezoelectric term comes from a Greek word piezein for pressure electricity. The piezoelectric effect exists in two domains; the first is the direct piezoelectric effect that describes the material's ability to transform mechanical strain into electrical charge, the second form is the converse effect, which is the ability to convert an applied electrical potential into mechanical strain energy. The direct piezoelectric effect is more suitable for sensor applications, whereas the converse piezoelectric effect is most of the times required for actuator applications [6]. The direct effect and the converse effect may be modeled by the following matrix equations:

Direct Piezoelectric Effect:

$D = d.\ T + E^T.\ E$ (1)

Converse Piezoelectric Effect:

$S = s^E.\ T + D_t.\ E$ (2)

Where D is the electric displacement vector, T is the stress vector, ε^T is the dielectric permittivity matrix at constant mechanical stress, s^E is the matrix of compliance coefficients at constant electric field strength, S is the strain vector, d is the piezoelectric constant matrix, and E is

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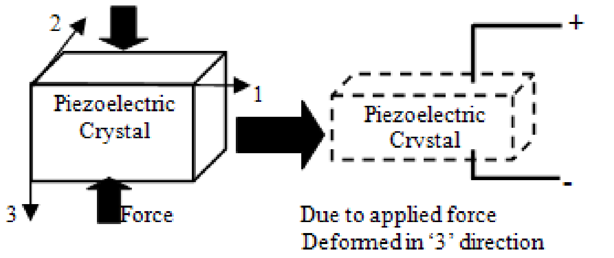
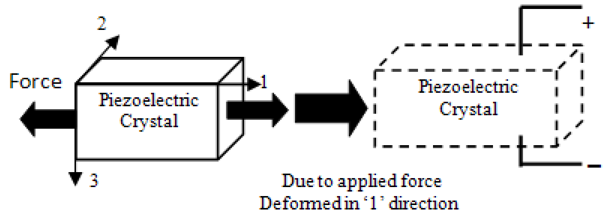
the electric field vector. The subscript t stands for transposition of a matrix.

There are two coupling modes for piezoelectric energy generators, these modes are understood by the direction of the mechanical force subjected on piezoelectric crystal and electric charge collected on electrodes. The direction of polarization is conventionally denoted as the '3' direction. As shown in Fig 2 (a), the '33' mode implies that charges are collected on the electrode surface perpendicular to the polarization direction when tensile or compressive mechanical forces are applied along the polarization axis.



(a)



(b)

Fig. 2 Modes of piezoelectric materials (a) '33' mode, (b) '31' mode

As shown in Fig. 2(b), the '31' mode implies that charges are collected on the electrode surface perpendicular to the polarization direction when force is applied along the direction perpendicular to the polarization axis [6]. For most piezoelectric materials, the coupling factor of the 33-mode, k33, is larger than the coupling factor of 31-mode, k31.In the 31-mode, the mechanical stresses are applied along the 1-axis. The stresses can be easily achieved by bonding the piezoelectric element to a substructure like rectangular metallic strip undergoing bending. The 33-mode energy conversion can achieve higher output power by increasing the layer of the ceramic (Stack type). For very low-pressure source and limited size, the 31-mode conversion may have a greater advantage in energy conversion [7]. For application of the shoes structure, the dimension of the harvester is less and the environmental sources for mechanical vibration energy are also limited. The 31-mode energy conversion is suitable for piezoelectric micro generators used in shoes structures.

I. PIEZOELECTRIC ENERGY HARVESTING SYSTEM

The vibrations energy harvesting principle using piezoelectric materials [4] is illustrated in figure 3. The conversion chain starts with a mechanical energy source as human motion using shoes. Human motion vibrations are converted into electricity via piezoelectric element. The electricity produced is thereafter converted by an AC-DC rectifier circuit and DC-DC step up converter before applying to a storage device.

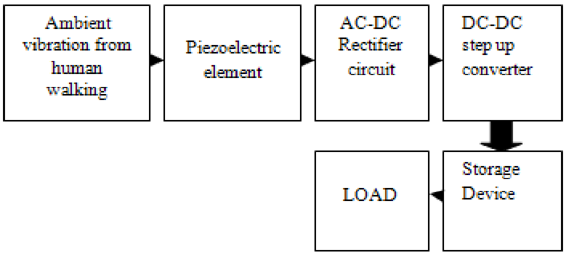
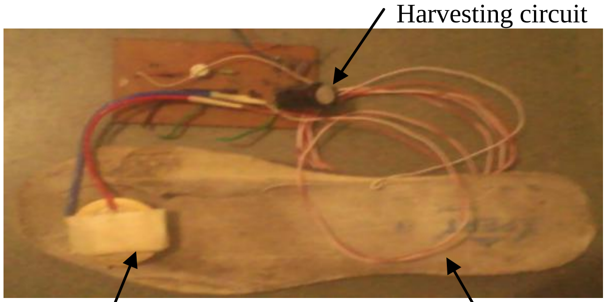


Fig. 3 Proposed Energy harvesting system

In this study, before developing inserted shoe piezoelectric harvester, it was essential to begin with a mechanical vibrations locations identification for doing the analysis output power, voltage and applied pressure. So we have carried out measurement by placing piezoelectric element on different locations of an experimental shoe sole Fig. 4 to identify the locations where more energy harvesting is possible. We could then develop a piezoelectric energy harvesting system.

Harvesting circuit



Piezoelectric Element

Inner shoe sole

Fig.4 Piezoelectric element locations on shoe sole

The piezoelectric element was place on various locations of the shoe sole and same pressure is applied on the piezoelectric element and output voltage is measured at the locations at heel, sole, between sole and heel and toes with the help of digital multi-meter. The location near the toes provided the maximum voltage by the single impact. Fig.5 shows the four locations where the single impact of pressure is applied and voltage is measured. The same measurement is done while walking with the same pace and an irregular function of time signal (i.e. AC) is observed on cathode ray oscilloscope as shown in Figure 6.

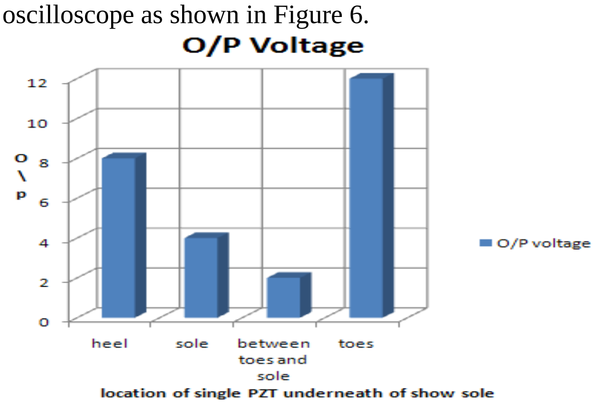


Fig.5 Measurement of o/p voltage at different locations

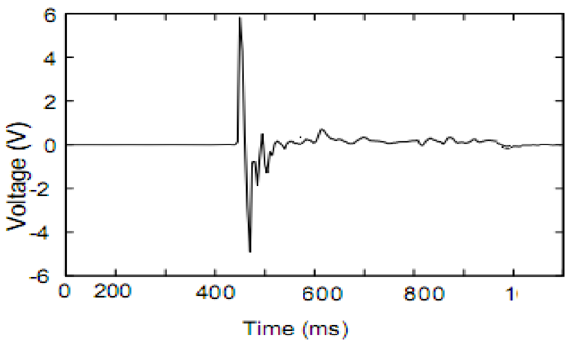


Fig. 6 Single step output voltage while walking

II. III. ELECTRICAL INTERFACE CIRCUIT

A. Rectifier circuit and DC-DC step up converter

From the fig.6 it is clear that the piezoelectric element generate a sinusoidal signal that can be applied to storage device as small portable battery. It is required to convert AC signal to stable DC signal. For converting irregular AC signal to DC signal a rectifier circuit having four Schottky barrier diodes are used as they have low forward bias voltage drop (i.e.0.33 volts) as compared to PN junction diodes (i.e.0.7 volts).As each cycle of applied input signal requires two diodes for rectifying the signals so the total voltage drop is doubled and energy harvested from piezoelectric harvester cannot be sensed properly by PN junction diodes. Further to harvest more electric energy from piezoelectric element a DC-DC step up converter is connected so that output of step up converter can be directly applied to the storage element. Step up converter action is based on switch which normally a transistor which is controlled by pulse applied on the base of the transistor. A inductor having value of 100mh is connected in series with the rectifier circuit and to a Schottky barrier diode to a storage element as capacitor as shown in fig.7 The complete circuit with piezoelectric element is placed into a shoe and further tests are performed with simulator and in real walking environment.

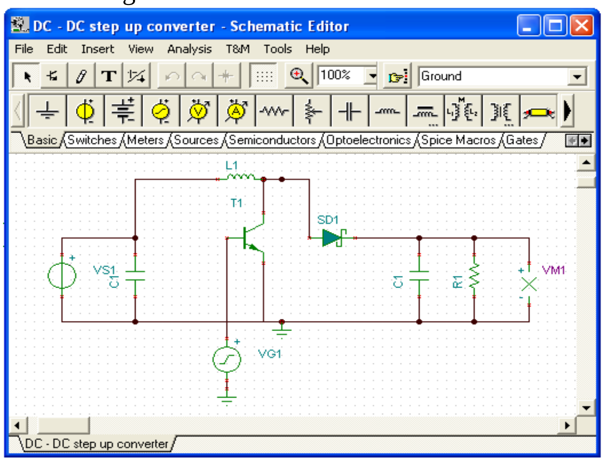


Fig. 7 DC- DC step up converter circuit

B. Experimental results in Tina simulator

From the experimental results performed by piezoelectric element and rectifier circuit, the output voltage obtained is 1.0 volts, but for testing the performance of DC-DC step up converter a DC voltage source having the minimum input of 0.4volt is chosen. From the simulation results the output voltage obtained is 2.45 volts. The efficiency of the overall system is 80 %.When the same circuit with piezoelectric element and rectifier circuit connected to the DC –DC step up converter was conducted in real walking environment ,the output of experimental results are nearly same. Simulation results are shown in figure 8.

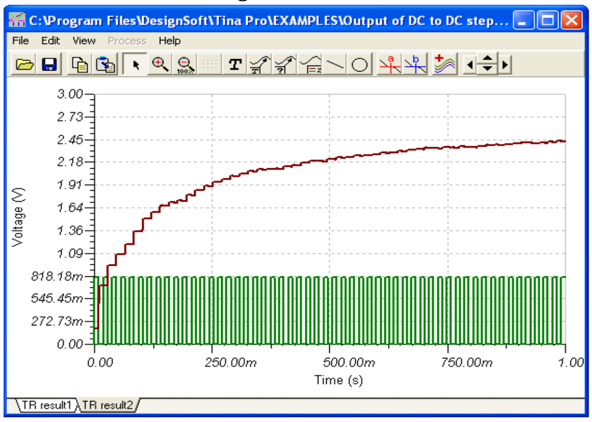


Fig.8 Simulation results of DC-DC step up converter

V. CONCLUSION

There are several methods available for harvesting human energy but from all methods piezoelectric energy harvesting is most promising method, piezoelectric materials associated with DC -DC step up converter provide maximizing the harvested energy. In particular, Piezo ceramic or PZT are especially interesting due to their low cost, flexibility and easy integration into elements such as shoes. In this paper PZT element are used to design an efficient energy harvesting system which is inserted into the sole of a shoe. Energy harvesting is possible using simple design and electronic circuit. For proper operation of portable electronic devices, improvement has to make in electronic circuit design to extract more energy from the human energy, in order to optimize the maximum energy transfer and number of the piezoelectric generators should be integrated into the sole of a shoe.

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