

## Power Harvesting Using Piezoelectric Shoe For External Power Storage

Mohammad Saffri Mazalan, Roslina Mohamad, Murizah Kassim, Shahrani Shahbudin

Fakulti Kejuruteraan Elektrik, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia

---

### Article Info

#### Article history:

Received Sep 24, 2017

Revised Dec 27, 2017

Accepted Jan 16, 2018

---

#### Keywords:

Piezoelectric

Polyvinylidene difluoride

Power harvesting

Power storage

---

### ABSTRACT

The demands for portable energy source have increased because most portable electronic device needs the extra energy throughout the day due to the user's increase in power consumption. Hence, a piezoelectric power harvesting shoe circuit with storage mechanism capabilities is designed by using piezoelectric disc material, 1N4007 bridge rectifiers, USB cables, and an external power storage. Piezoelectric disc material of 27mm and 35 mm in size that produces AC voltage when applied pressure is embedded in shoe's insole and the output AC voltage is converted using a bridge rectifier for each material. The output is connected to a USB cable and can be connected to the external power storage during power harvesting. Different sizes of piezoelectric disc produce different amount of voltage and are also affected by the pressure applied to it. An amount of 5V is the requirements needed to charge an external device. The 27mm disc produces a voltage of 3V to 5V depending on the pressure applied while the 35mm disc produces 4V to 6.2V. Piezoelectric disc material is an alternative way to harvest energy when embedded to a shoe with an added storage capability as it solves the problem of needing the extra energy for electronic devices.

*Copyright © 2018 Institute of Advanced Engineering and Science.  
All rights reserved.*

---

### Corresponding Author:

Roslina Mohamad,

Fakulti Kejuruteraan Elektrik

Universiti Teknologi MARA

40450 Shah Alam, Selangor, Malaysia.

Email: roslina780@salam.uitm.edu.my

---

## 1. INTRODUCTION

Piezoelectric material generates voltage when a mechanical stress is applied and was discovered by the Jacques and Pierre Curie brothers in 1880 [1]. Piezoelectric ceramics is a ferroelectric material that has spontaneous electric polarization. The material may undergo mechanical deformation when an electric field is applied. Most crystal or solid has a symmetrical repeating arrangement of atoms. For a material to exhibit piezoelectricity; it requires the crystal to have no center of symmetry. The atoms inside the piezoelectric crystal have balanced electrical charges and are electrically neutral. If the structure forcefully undergo deformation, the negative and positive is imbalance thus causing electrical charges of net positive and negative charges appear on outer part of the crystal [2]. The ambient vibration is transformed into electrical energy and is stored to power up electronic devices and requires no external voltage sources.

Multiple developments of piezoelectric power harvesting embedded in shoe has been done as an alternating power source as it can extract ambient vibration and converts it into electrical charges when mechanical stress is applied to it. For instance, the simulation and experimental results of energy harvesting circuit and efficiency of the extracted ambient vibration energy by lead zirconate titanate ( ) also called PZT, in terms of electrical voltages during single step and continuous walking for a period of time has been done [3]. By placing piezoelectric elements on various locations of the shoe sole and applied the same pressure the maximum voltage level is recorded by using a digital multi meter. Placing the piezoelectric under the toes

provides the maximum voltage by the single impact compare to placing it under heel, sole and area between toes and sole.

Polyvinylidene difluoride (PVDF) is also a type of piezoelectric material that has considerable flexibility, good stability, and is easy to handle and shape. If a researcher considers the human motion characteristics of high amplitude and low frequency, PVDF is more appropriate for wearable applications than PZT. PVDF has been used in wearable energy harvesters and implemented in shoe [4]. When a force is applied on the upper plate, the upper plate is pushed down thus stretching the PVDF layer on one axis. Due to the deformation of the layer, electrons are now imbalance and accumulated in the upper and lower side of the layer [5].

Another approach of energy harvesting by walking is by using both the PZT and the PVDF material combined. Energy is extracted from foot striking and flattens the curved, pre-stressed spring metal strips laminated with a semi-flexible form of PZT under the heel while a multilaminar PVDF bimorph stave mounted under the insole [6]. At walking speed, the PVDF stave generates an average power of 1.3mW in a 250-k $\Omega$  load at a 0.9-Hz frequency. Contrariwise, the PZT dimorph generates an average of 8.4 mW in a 500-k $\Omega$  load under identical activity. The stride aspects are significant in these plots. The huge increase in power at certain points indicates the device's accelerated initial bending or compression. Meanwhile, when the walker move casually and shifts his weight to the opposite foot, smaller rise are observed representing transducer renewal [6].

Most of the research focuses on the generation of energy by walking but does not conserve the wasted energy [7]-[9]. Without the addition of power storage capabilities, energy produced by the piezoelectric elements will be wasted when electronic devices are not connected. In addition, energy generate continuously while the users are walking and is not conserved and stored. Hence, the aim of this paper is to harvest energy by designing a shoe embedded with piezoelectric discs element. To conserve the renewable energy, an external power storage is added as the output of the circuit as energy conservation and is able to recharge electronic devices. Thus, a storage capability is analyzed and implemented for the piezoelectric power harvesting shoe circuit.

## 2. PROTOTYPE OF POWER HARVESTING PIEZOELECTRIC SHOE

In this research, the system works by having mechanical stress applied to a PZT piezoelectric disc 25mm to 37mm in size to produce ambient vibration by walking and is then converted into electrical energy via mechanical deformation of the piezoelectric elements. Then, the AC voltage is converted into DC through AC-DC rectifier circuit consisting of 1N4007 diodes. The supplied power is then stored in an external storage before being connected into a rechargeable mobile device via USB cable. Two different sizes of 27mm and 35mm in Figure 1 of piezoelectric disc was tested using a multi-meter and the AC voltage generated from each disc during 8 continuous stepping based on the type of steps applied to it. Every test was done twice to find the average mean of AC voltage and current values is then recorded. The piezoelectric ceramic was hooked together in parallel or series before connected to the bridge rectifier.



Figure 1. 35 mm disc is place on the left, 27mm disc is placed on the right

Figure 2 shows the circuit design consisting of 6 piezo elements embedded in shoe's insole place in the toes and the heels. Each piezo elements is connected to a bridge rectifier. Three discs are placed at the toes and three are placed at the heel. As mentioned before, during the motion of walking, the first step a human takes cause pressure to the surface area of the heel. During shifting, pressure occurs in the section of the toe leaving the section of the heel untouched.

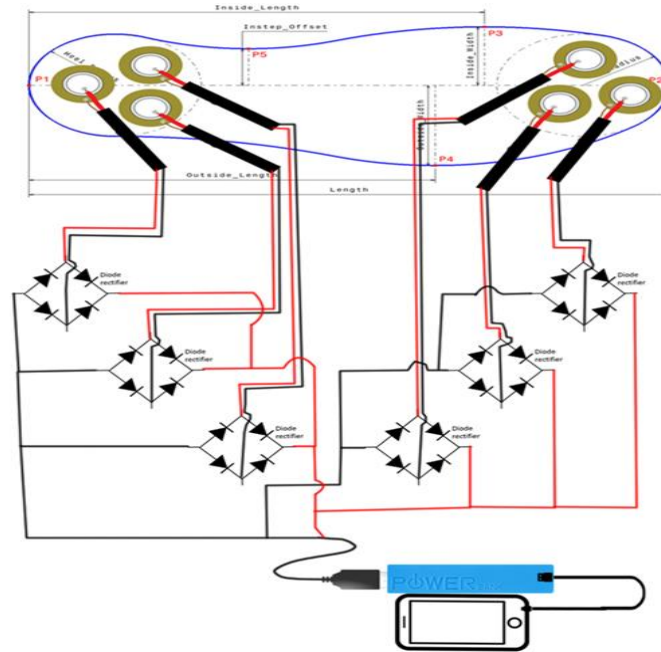


Figure 2. Circuit design of power harvesting piezoelectric shoe for external power storage

Figure 3 shows the piezoelectric shoe prototype is designed by using the 35mm piezoelectric discs positioned at the heel and the toe. It is then implanted in a Nike SB shoe and the shoe's insole where the piezoelectric materials are placed is created using a mounting board. Each piezoelectric disc is connected to a bridge rectifier. Every rectifier is the paralleled together and connected to a USB cable. The USB cable is then connected to any external power storage. Figure 4 shows the actual prototype of the system with the piezoelectric disc embedded on the shoe's insole and tested with bulky external power storage. It is recommended to use a smaller power bank so that it is easier to be implanted inside the shoe.



Figure 3. Prototype of piezoelectric shoe



Figure 4. Prototype of piezoelectric shoe with external power storage

### 3. RESULTS AND DISCUSSIONS

Table 1 shows the result of average mean DC output voltage for 27mm disc during 8 continuous light steps. The amount of voltage per step increases as the number of plates increase. By using a single disc, the amount of voltage produced is 0.68V. However, by using 3 discs it produces 2.48V thus proving that more discs generate more electricity.

Table 1. DC Output Voltage Test From 27 mm Disc During Light Steps

Number of disc used	Average mean voltage(V)
1	0.637
2	1.850
3	2.448

Table 2 shows the result of average mean DC output voltage for 27mm disc during 8 continuous casual steps. With casual steps, the discs produce more voltage as compared to walking in light steps. Even at a single disc, the average mean voltage produced is 1.9025V due to higher pressure. Then, 3 discs produce much more voltage which is 5.068V.

Table 2. DC Output Voltage Test From 27 mm Disc During Casual Steps

Number of disc used	Average mean voltage(V)
1	1.903
2	3.631
3	5.068

Table 3 shows the result of average mean DC output voltage for 35mm disc during 8 continuous light steps. With the use of the 35mm piezo disc, the output voltage and current during light stepping is higher compared to the 25mm proving that the 35mm is more viable to be used for power harvesting. A voltage of 1.888V is produced using only 1 disc, and a maximum of 2.966V is produced using 3 plates.

Table 3. DC Output Voltage Test From 35 mm Disc During Light Steps

Number of disc used	Average mean voltage(V)
1	1.888
2	2.623
3	2.966

Table 4 shows the result of average mean DC output voltage for 35mm disc during 8 continuous casual steps. Tables 4 proves that the voltage value is higher in casual steps and is enough to power up and charge a power storage that requires a 5V input because just by using a single plate, the output voltage is 4.212V. Furthermore, by using 3 discs, 6.233V is produces and is enough for external devices.

Table 4. DC Output Voltage Test From 35 mm Disc During Casual Steps

Number of disc used	Average mean voltage(V)
1	4.212
2	4.970
3	6.233

From Tables 1 to 4, the voltage level does depends on the size of the piezoelectric materials and the pressure applied to it. The 35mm produces more voltage as compared to the 27mm and having larger total surface area. The 35mm produces a maximum of 6.233V while the 25mm produces 5.068V at casual walking and by using 3 piezoelectric discs. Therefore it is more viable to use the 35mm as compared to the 27mm for the final design of the piezoelectric shoe. The no. of disc affects the average mean output voltage produced however having more than 4 disc to a bridge rectifier would reduce the output voltage by a significant amount because the discs cancel each other's output voltage when not actuated at the same time. Therefore, each piezoelectric disc is designated its own bridge rectifier then it is connected in parallel.

The result of this test includes the findings of the AC voltage generated from each disc during 8 continuous stepping based on the type of steps applied to it. Every test was done twice to find the average mean of AC voltage and current values is then recorded. The piezo material AC voltage individual testing is as shown in Table 5. It is observed that the piezo disc produces AC voltage per step and is affected by the size of the disc.

Table 5. Piezo Material AC Voltage Individual Testing

Size (mm)	Resonant frequency (kHz)	Capacitance (kpF)	Average mean AC voltage (V)	
			Casual steps	Light Steps
27	4.6 +/- 0.5	16	+/- 1.9045	+/- 0.656
35	2.8 +/- 0.5	30	+/- 2.706	+/- 1.689

The 35 mm disc produces a higher AC voltage compared to the 27mm disc. It is also affected by the type of foot strikes applied after continuous walking. It is observed that casual steps produces higher AC voltage level. The prototype was managed to be done by using 6 35mm piezoelectric disc. Three discs are placed at the toes and three are placed at the heel. As mentioned before, during the motion of walking, the first step a human takes cause pressure to the surface area of the heel. During shifting, pressure occurs in the section of the toe leaving the section of the heel untouched. Therefore for continuous generation of electricity, the piezo disc is placed on both the toe and the heel. The 35mm disc produces more output voltage compared to the 27mm making a better candidate to be used in the shoe's insole for power generation. Furthermore it manages to supply the requirement of 5V of power banks. reader understand easily [2], [5]. The discussion can be made in several sub-chapters.

#### 4. CONCLUSION

The piezoelectric power harvesting shoe is a good source for renewable energy for energy conservation. As observed, by using a 35mm piezo disc, it produces enough voltage to recharge an external storage device that requires 5V of input. The 25 mm disc is viable for power harvesting but does not meet the requirements to charge up an external storage device. Furthermore, it is inexpensive, flexible and can be easily integrated in mediums such as shoe. Types of pressures do affect the amount of voltage used. Casual walking produces enough voltage to power up the external storage device. With power storage device, the amount of energy produce will not be wasted as it is stored constantly during walking. Further improvement can be made to the piezoelectric shoe such as using a better piezo ceramic material that produces more current. However, this shoe is not water resistant thus water would damage the circuit.

#### REFERENCES

- [1] Van Randerat J and Settingington RE. Piezoelectric ceramics *Electronic Components and Materials Division*. N.V. Philips' Gloeilampenfabrieken, Eindhoven, p. 202, 1974.
- [2] Piefort V and Preumont A. *Finite Element Modelling of Piezoelectric Active Structures*. Samtech User's Conference. 2001. 154.
- [3] Gupta A and Sharma A. Piezoelectric Energy Harvesting via Shoe Sole. *International Journal of New Technology and Research*. 2015; 1(6): 10-13.
- [4] Zhao J and You Z. A shoe-embedded piezoelectric energy harvester for wearable sensors. *Sensors (Basel)*. 2014; 14(7): 12497-510.
- [5] Kymissis J, Kendall C, Paradiso J and Gershenfeld N. *Parasitic power harvesting in shoes*. Second International Symposium Wearable Computing. 1998; 2-9.
- [6] Shenck NS and Paradiso JS. *Energy scavenging with shoe-mounted piezoelectrics*. IEEE Microwave. 2001; 21(3): 30-42.
- [7] Pankaj Aswal, Suyash Kumar Singh, Gayatri Sharma, Pooja Bisht and Shatakshi Singh. Generation of Electricity by Vibrating Piezoelectric Crystal in Staircases. *Indonesian Journal of Electrical Engineering and Computer Science*. 2017; 6(2): 219-224.
- [8] Aqsa Abbasi. Application of Piezoelectric Materials and Piezoelectric Network for Smart Roads. *International Journal of Electrical and Computer Engineering*. 2013; 3(6): 857-862.
- [9] Shuai Pang, Wenbin Li and Jiangming Kan. Simulation Analysis of Interface Circuits for Piezoelectric Energy Harvesting with Damped Sinusoidal Signals and Random Signals. *TELKOMNIKA*. 2015; 13(3): 767-775.