

Principle and Experimental Study of Human Energy Harvesting Through Piezoelectric Ceramic

Jiacun Sun^{1,a}

¹Electronic and Informational Engineering Department, Suzhou Vocational University, Suzhou 215014, China

^ajiajun_sun@163.com

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Abstract. When under pressure, the piezoelectric materials produce electric charge on its surface, the foot continuously produce pressure on the earth when human is walking, if the shoes fitted with piezoelectric ceramics, piezoelectric ceramics is continuously under pressure, and Continuously generate charge, The electrical energy is stored by the electrical energy storage circuit, after be stabilized, the electrical energy can recharge the rechargeable battery. This paper studies the body acquisition principle of the piezoelectric ceramic energy, the piezoelectric ceramic energy acquisition experimental setup is designed, the device structure is simple, experiments were carried out, and experimental results show that the device is ideal for charging to the mobile electronics, power or other portable medical devices power.

Introduction

Piezoelectric material in the polar deformation will produce a voltage, when a voltage is applied to the piezoelectric material, piezoelectric material will produce distortion, which is the capacity characteristics of the piezoelectric material. The characteristics of electricity generated by piezoelectric materials' deformation is high-voltage, low current, so the piezoelectric material is generally as a transducer, the application of sensors such as microphones, tweeters, piezoelectric pressure sensors, piezoelectric acceleration sensors applications. The foot will continuously produce pressure on the ground when human body walking, if the pressure was on the piezoelectric ceramics, piezoelectric ceramics will continuously generate electricity, if the electrical energy is storage down, the electricity production can be easily, cost low, green, and pollution-free. How to convert the kinetic energy of human body movement into electrical energy, some studies have been carried out, [1] designed a piezoelectric power generation shoe, the main force by a steel ball, resulting in piezoelectric materials by horizontal pressure, and resulting in voltage, the thickness of the piezoelectric material in the design is high, and the cost is expensive, and the piezoelectric material is designed in shoe, and production is not convenient, the higher cost of products made. The electric power is produced through knees cyclical movement of oppression piezoelectric ceramic, its structure is complex; the processing is difficulty; and high cost of products made. Abroad-related research [3] [4], but the power generation equipment by the study design of the body have high cost, low energy, there is little formation of related products. This paper research the generating mechanism of piezoelectric material, and designs a piezoelectric power generation device, the piezoelectric ceramics is placed in the insole, the external circuit through the wire leads shoes outside, the integrated circuits is placed outside of the shoes, the processing is easy, and easy to replace, low cost, easy-to-production processes, the regulator circuit is designed, and experiment has be done, and experimental results show that the initial use of piezoelectric energy harvesting devices by this method can be made to charge the battery for continuous and intermittent charging, which has great practical significance.

Narrate the principle

After the polarization of the piezoelectric crystal material, when under pressure, the piezoelectric crystal will produce deformation, the piezoelectric crystal on both sides of the conductive layer will

produce charge, and produce the voltage, the piezoelectric crystal can be equivalent to a capacitor and a resistor in parallel, the capacitance is very small, the parallel resistance value is very large^[5]
^[6]. The pressure and the voltage generated by the piezoelectric crystal $v_g(t)$ can be expressed as:

$$v_g(t) = (f(t) / A) \times h / G_{33} \quad (1)$$

Or

$$v_g(t) = d_{33} \times f(t) / C_p \quad (2)$$

Where $f(t)$ -pressure; A -crystal surface area; h -crystal thickness; G_{33} -piezoelectric voltage constant; d_{33} -the piezoelectric strain constant; C_p -piezoelectric crystal equivalent capacitance, the value is:

$$C_p = K \times A / h \quad (3)$$

In this formula, K -dielectric constant, the weight of the human body is fixed, every time the force is applied to piezoelectric crystal is basically fixed, is set as F , the generated voltage by piezoelectric crystal each force is fixed, is set as V_g :

$$V_g = \frac{(F / A) \times h}{G_{33}} \quad (4)$$

The energy is produced by piezoelectric crystal:

$$E_g = 1/2 \times C_p \times V_g^2 \quad (5)$$

The piezoelectric voltage is very high, but the piezoelectric equivalent capacitance is small, the current is small, when the pressure is removed, the charge above the piezoelectric crystal will disappear, the voltage is generated by piezoelectric crystal can not be directly used, when the electric energy is saved through the energy storage components, which can be used, classic electric energy acquisition is shown in figure 1, in this map, the piezoelectric crystal can be equivalent to a capacitor and a resistor connected in parallel, wherein R_d is the equivalent resistance of transmission line, design C_s of circuit (called the storage capacitance), when the piezoelectric crystals by positive force will generate charge, through the bridge to the C_s charging, with piezoelectric crystal voltage drop, after unloading, deformation of piezoelectric crystal recovery, the piezoelectric crystal is equivalent to a reverse force, and produce reverse voltage, through a bridge for C_s positive charge, so as to achieve the two charging effect.

After Piezoelectric crystal under force, will produce charge, the voltage is high otherwise the voltage on the storage capacitor is low. The charge moves to storage capacitor, set the voltage on the storage capacitor C_s as V_s , when the voltage on the capacitor C_s is equaled to the voltage on the piezoelectric crystal C_p , the charge moving stops^[7], then $V_p = V_s$, assuming the piezoelectric ceramic equivalent resistance is very greatly, as open, by the law of conservation of charge to:

$$V_s = (C_p \times V_g) / (C_s + C_p) = \frac{(F / A) h C_p}{(C_s + C_p) G_{33}} \quad (6)$$

Set the ultimate energy on the storage capacitor as E_s , then:

$$E_s = 1/2 C_s V_s^2 \quad (7)$$

When $C_s \gg C_p$, then the equation (7) can be transformed into:

$$E_s = \frac{C_p^2 V_g^2}{2 C_s} \quad (8)$$

The energy transfer efficiency:

$$\eta = \frac{C_p}{C_s} \quad (9)$$

By 6, 8, 9 shows, when the pressure is fixed, after each compression, capacitor storage energy is decided by the thickness of piezoelectric crystal, and the piezoelectric parameters, storage capacitance, the storage capacitor is smaller, the transfer voltage is greater, and the energy transfer

efficiency is higher, DC input voltage can not be too high, so the value of the storage capacitor can not be too small, if the capacitance is too small, the discharge time is too short. When decide the storage capacitor value, the piezoelectric ceramic to the storage of rechargeable energy exactly equal to the load energy consumption in a cycle.

Experimental study

When the body walking, the forefoot and rear foot have applied pressure to the ground in different time, when design the piezoelectric films structure, each piezoelectric film is placed in the front and rear of the insole, piezoelectric film is PZT-51 material, double-crystal structure of the board, substrate for the structure is copper, the piezoelectric material is placed on both sides, copper of 45mm diameter, piezoelectric film, diameter is 35mm, thickness is 0.20mm, the whole piezoelectric film thickness is 0.6 mm; The performance parameters of the piezoelectric material as follows: the permittivity ϵ_{33}^T is $2 \times 10^{-8} \text{F/m}$, the piezoelectric constant d_{31} is $-88.1 \times 10^{-12} \text{C/N}$; d_{33} is $450 \times 10^{-12} \text{C/N}$; elastic modulus of the piezoelectric material E_p is $8.2 \times 10^{10} \text{N/m}^2$, the copper elastic modulus E_m is $12.4 \times 10^{10} \text{N/m}^2$, the density of copper ρ_m is $8.8 \times 10^3 \text{kg/m}^3$, the density of the piezoelectric ceramic ρ_p is $7.6 \times 10^3 \text{kg/m}^3$. The produced voltage is leaded out through the wires, because the time of the front and rear legs to the ground, is not the same point, in order to ensure that electricity generated gave the storage capacitor charging, two bridge rectifier circuit in the circuit are designed, common on charge the storage capacitor, the voltage regulator chip is Maxim's MAX1921, MAX1921 buck converter can output the minimum voltage to 1.25V, while providing more than 400mA current. Availability of more than 90% efficiency, the input voltage range is 2-5V. In order to ensure that the voltage to a rechargeable battery charging, designs regulator 1.5 output, the design of the circuit shown in Figure 2, in order to ensure the regulator chip does not exceed the input voltage of 5V, one 5.0V regulator is placed between the input of the regulator chip and the indirect, the SHDN port is connected to the input side, when it is low, the voltage regulator chip stop working, the input current is approximately 0A, when the storage capacitor voltage rises to 2V, the regulator chip begin work, this can control voltage regulator chips start to work well and improve the energy transfer efficiency of the regulator chip, the design of experiments schematic diagram is shown in Figure 2.

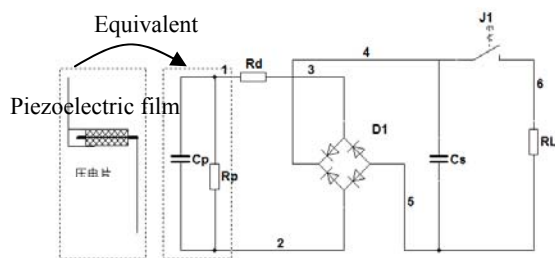


Fig.1 piezoelectric oscillator equivalent circuit chart

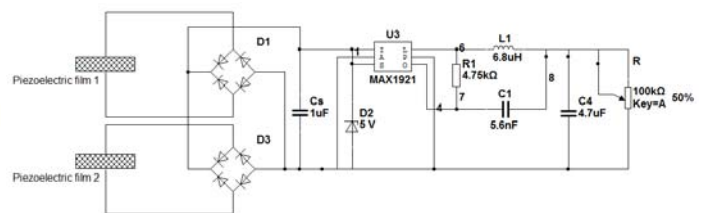


Fig.2 Experimental schematic

The circuit experiment is designed and confirmed, the experiment of device as shown in figure 3. The following experiments are done:

1) the piezoelectric vibration piece by a 70Kg of normal human walking generates a voltage waveform, dual channel data acquisition card for collecting waveform, as shown in figure 4, the above graph is voltage waveform generated by the hind paw, the low graph is voltage waveform generated by the forefoot paw, the figure can be seen that two voltage waveform is different, the time is somewhat inconsistent, a generated voltage can reach above 30V;

2) Test with a load capacity of the system in Figure 2, the capacitance C_S is recommended to be 22 μF , 33 μF , 47 μF , 100 μF , 10 μF , and test, using a multimeter to test the voltage across the load, to adjust load from the 100k down 0, and test output voltage, when DC converter output voltage is less than 1.5V, the resistance is the maximum load capacity, been tested, when the storage capacitance is 33 μF , the resistance value of the minimum is 6.2K, the power generator output power is 0.36mW,

this time the testing storage capacitor and the voltage across the load are shown in Figure 5, can be seen that the storage capacitor voltage value is instable, but the voltage across the load is constant, and achieve the effect of regulated voltage value, On every cycle of the storage capacitor voltage is the basic fixed, description that in a cycle, piezoelectric ceramic charging energy to storage capacitor basic equal to the load consumption of energy.

3)DO intermittent charging experiment, when the load is 3K, normal human walking test and test storage capacitor voltage and the voltage across the load, it can be seen form figure 6, at every step, the storage capacitor voltage increases, when up to two volts, the voltage regulator chip begin work, supply load energy, then the storage voltage begin drop, the storage capacitor voltage value decreases, and the voltage regulator chips stop working, so as to achieve the effect of intermittent charging.

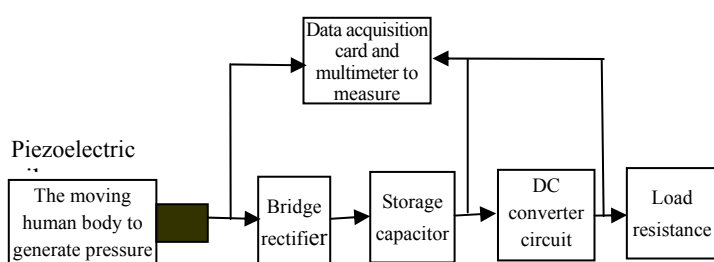


Fig.3 Experimental setup

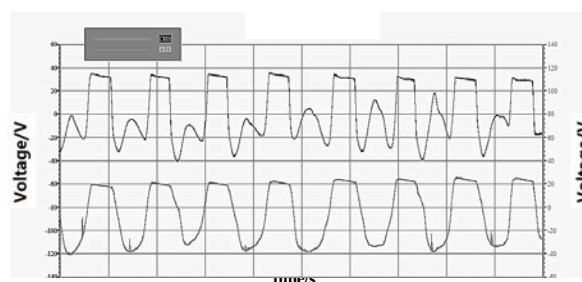


Fig.4 the voltage waveform produced by the two piezoelectric sheet

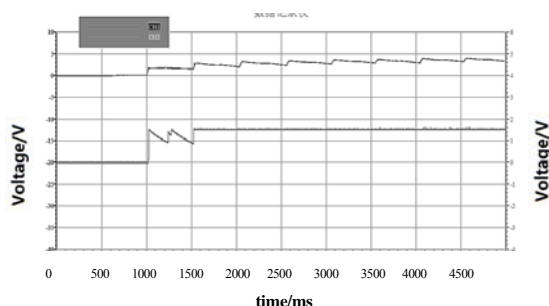


Fig.5 The storage capacitance and the load voltage waveform in the case of maximum load

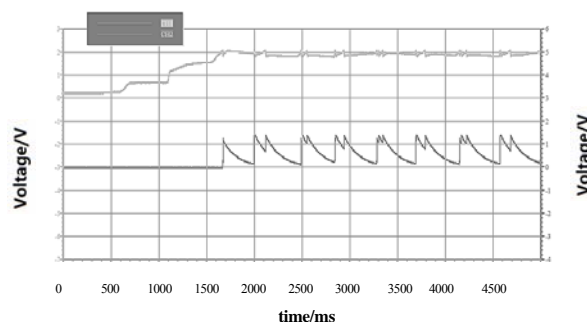


Fig.6 The voltage waveform across the load in the case of intermittent charging storage capacitor

Summary

Piezoelectric material is inexpensive and has stable performance. When human body is walking, this will produce fixed pressure on ground, which is equivalent to the human body continued to do power on ground. If the energy is collected to use as a circuit power, then it is of great significance. In this paper, the principle of Piezoelectric film producing power is studied, the transfer relationship between piezoelectric patch and the storage capacitor is derived, the storage capacitance value that influenced the size of piezoelectric energy transfer efficiency, this paper gives design of piezoelectric acquisition circuit, the piezoelectric pieces are arranged in the insole, convenient installation, wearing comfortable, while occupying space, easy replacement, low cost, after the experiment, if the capacitance is suitable, the equipment can produce 0.36mW power, if connected with a rechargeable battery, can be intermittently to charge the rechargeable batteries, ensure the recharge, the design of device can give mobile consumer electronic battery, some medical design of the battery charging, it is green environmental protection, easy to be made and manufactured, is low cost.

References

- [1] CHU Jin-kui, wei Shuang-hui, DU Xiao-zhen et al. One power generation shoe [P]. China, 200710158678.2. 2008.10.
- [2] YAO Yong-gang, YAO Meng. Design and Experimental Study of A Human-body Energy Conversion System Based on Piezoelectric Ceramic[j]. Machine Design and Research, 2011(12):34-36.
- [3] Starner T. Human-powered wearable computing[J]. IBM Systems Journal, 1996,35:618- 629.
- [4] Kymisis John. Parasitic power harvesting in shoes[J]. Physics and Media Group MIT Media Laboratory, 2001:30-35.
- [5] Sun Kang, Zhang Fu-xue. Piezoelectricity. National Defence Industry Press[M], 1984,80-160.
- [6] huang Zhe-xi. Functional materials and application manual. Mechanical Industry Press, 1991,300-486.
- [7] Oberlin, et al. One-shot high-output piezoid power supply[P]. United States Patent, 6198205, 2001.3.