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Design of Energy-saving Power Generation Shoes for Outdoor Sports based on Piezoelectric Ceramics

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Abstract

In the 21st century, the rapid development of science and the convenience of life are greatly improved, but the situation of non-renewable energy production is grim. In order to improve the transformation of green energy and low-carbon, and actively respond to the national low-carbon energy-saving policy, this paper proposes a new type of walking power generation device, which is based on piezoelectric ceramic outdoor energy-saving power generation shoes. The system includes pressure power generation module, rectifier filter module, booster module, energy storage module and power control module. The use of bending can generate electricity piezoelectric ceramic sheet, outdoor exercise when the sole piezoelectric ceramic sheet deformation produces a larger pulsating AC, each piece of piezoelectric ceramic access diode does not control single-phase bridge rectifier circuit, the AC rectifier into DC, and then access the filter capacitor and boost circuit, so that the circuit output 5V DC smoothly, after connecting the load part, Here we use the lithium battery and charge management chip TP4057 (500mA linear lithium battery charger) to supply power to the battery. The electric energy is finally transmitted to the GPS positioning system, heating plate and other load modules, and can be directly used to supply power to wearable electronic devices through the type-c interface.

Keywords

Piezoelectric Ceramics; Piezoelectric Effect; Pressure Power Shoes; BOOST Chopper; Energy Saving and Emission Reduction.

1. Introduction

In today's world, energy conservation and environmental protection have become an important issue, and how to efficiently use the body's own energy has become the focus of scientific research. Many scientists are working on ways to store the kinetic energy of walking and convert it into electricity. Since 1992, when L.A. Gear introduced a shoe that generates electricity, children have been able to make their shoes glow with electricity generated by their feet. But for most adults, the environmental energy generated by the simple act of walking is not utilized, which is a huge waste. Tom Krupekin and ASHLEY Taylor, professors of the Department of Mechanical engineering at the University of Wisconsin, reported in the August 23, 2011 issue of Nature Communications that they use reverse electrowetting technology, which compresses the current generated by the up and down movement of the foot while walking. This method can generate up to one kilowatt of electricity, but its power generation is unstable and difficult to collect and use. It is difficult to charge small portable devices, which does not conform to the concept of the source of power generation shoes. In 2015, scientists at a research center in Felingen-Schwenningen, Germany, proposed a "magnetic shoe," which uses the motion between a magnet and a coil to generate electricity, but it emits only 1 to 4 milliwatts of electricity. It can't generate enough electricity to charge a smartphone. Through comparative study, this paper designs and develops walking and charging power shoes using piezoelectric

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ceramics. The shoe sole has a built-in piezoelectric ceramic, which generates electricity for the pressure of the sole when walking, and the electricity generated can charge small devices such as GPS, batteries and type-c charging ports carried on the shoes. The experiment proves that this shoe has high conversion efficiency and meets the demand of energy saving and emission reduction. The charging device is fixed on the shoe and carried everywhere, which perfectly meets the original idea of the power generation shoe.

2. Principle of Pressure Power Generation

2.1. Piezoelectric Effect

In 1880, the French physicists Curie brothers found in the study of the physical properties of quartz crystals that when the chip is subjected to a force in some direction, the two opposite surfaces will have equal amounts of positive and negative charges when the chip is deformed. This phenomenon is called piezoelectricity. The medium that can produce this phenomenon is called a piezoelectric. [1, 2]There are two types of piezoelectric effects: positive piezoelectric effect and inverse piezoelectric effect. The two piezoelectric effects are shown in Figure 1 and Figure 2.

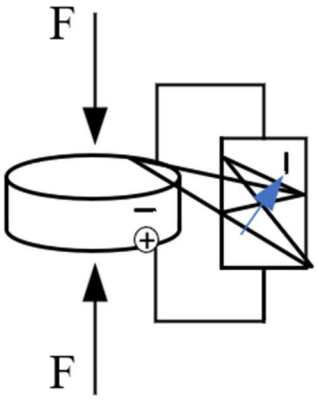

Figure 1. Positive piezoelectric effect

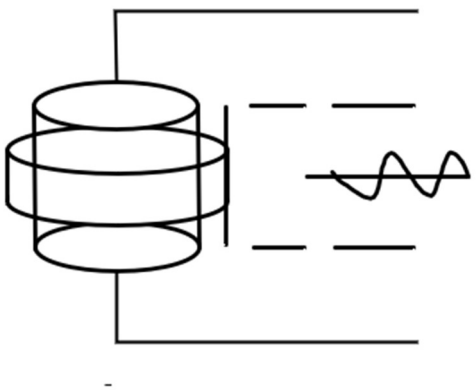

Figure 2. Inverse piezoelectric effect

ISSN: 2664-9640

2.2. Introduction to Piezoelectric Ceramics

2.2.1. Power Generation Principle

Piezoelectric ceramic is a kind of hard and brittle ceramic material formed by sintering at high temperature, which can convert mechanical energy and electric energy into each other [2]. See Figure 3.

The power generation principle of the piezoelectric ceramic plate is based on the above piezoelectric effect. Under the action of external force, piezoelectric ceramics produce a certain degree of deformation, and the surface charge changes, so that the opposite symbol of the charge appears at both ends of the material, and then the electrical property is displayed to the outside world, that is, the piezoelectric effect. At the same time, if the electric field with the same direction of polarization is applied to the piezoelectric ceramics, the polarization of the crystal is strengthened and stretched along the direction of polarization, resulting in deformation, which is an inverse piezoelectric effect.

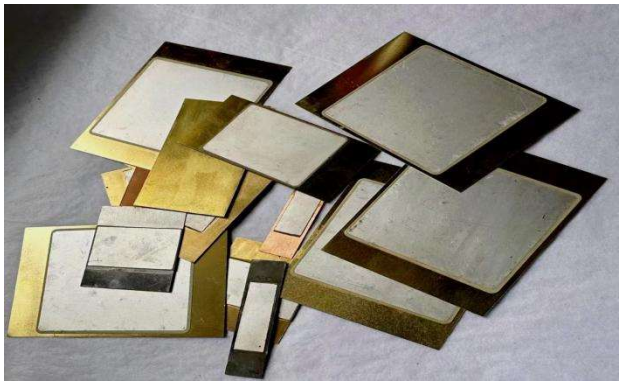

Figure 3. Piezoelectric ceramic plate

2.2.2. Application Prospect of Piezoelectric Ceramics

Piezoelectric ceramic sheet is a simple and lightweight electrical device, but also an important energy exchange material and engineering ceramic material, while with high strength, high hardness, high temperature resistance, corrosion resistance and other physical and mechanical properties as well as excellent electromechanical coupling performance, is a variety of sensors, transducers, electronic devices of the core components. It is widely used in electronic information, electromechanical energy exchange, automatic control, MEMS, medical industry, industrial production, aerospace and other cutting-edge fields [3].

3. Overall Design of Power Generation Shoes based on Pressure Ceramic Plate Power Generation

3.1. Overall Frame Design

The system is composed of six parts. The overall frame structure is shown in the circuit topology in Figure 4. The piezoelectric ceramic plate generates electricity. Each piezoelectric ceramic plate is connected to a diode rectifier bridge to convert the alternating current emitted from the piezoelectric ceramic into direct current. Then the power is supplied to the positioning module, and the type-c interface is used to power the wearable electronic device.

ISSN: 2664-9640

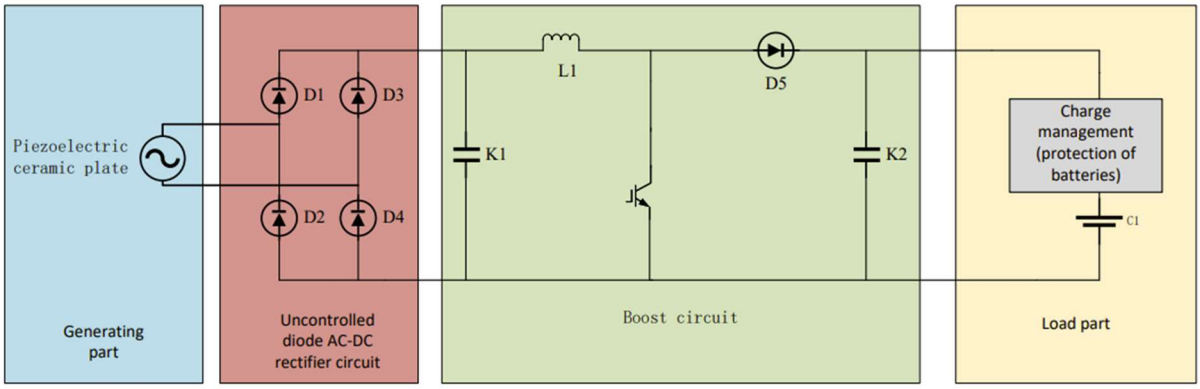

Figure 4. Topological structure

1) Each piece of piezoceramic individual power generation can emit an average 30V AC voltage, how many V DC voltage after connecting the rectifier bridge, 14 pieces of piezoceramic pieces together, the circuit integration (add load and filter capacitance), can stable output 2.4V voltage.

2) Rectifier bridge: Because the walking power generation can be manually controlled off, the rectifier bridge uses the LB10S chip whose device is a diode.

3) Filter capacitor: After 0~2200UF size capacitor selection, the final selection of 470UF filter capacitor, can be stable and efficient filtering, and fast charging time and output flat direct current.

4) Booster circuit: Using chip MP28164GD-P, the input voltage of 2.4V is increased to 5V output.

5) Lithium battery: Choose 18650 lithium battery, rated voltage 3.7V, rated capacity 2000MAH.

6) Charge management chip: TP4057 chip is selected to protect the battery.

3.2. Control Strategy

3.2.1. Power Generation and Rectifier Filter Module

Pressure power generation using 14 pieces of piezoelectric ceramics for pressure power generation, divided into two groups, each group of seven in series, the last two groups in parallel, each piece of piezoelectric ceramic connected to a rectifier bridge for rectification, after rectification connected to 470μF electrolytic capacitor for filtering. That is, using the combined action of the rectifier diode and the capacitor, the AC current with a lower voltage amplitude is changed into a DC voltage with a higher voltage.

3.2.2. Boost Module, Energy Storage and Charge Management Module

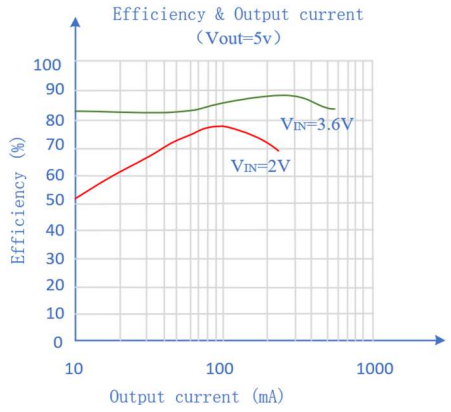

Figure 5. Relation between output current and efficiency

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1) Booster module: High efficiency synchronous HX3002 chip is used to boost the voltage, as shown in Figure 5, with high overall efficiency. The figure shows the relationship between its efficiency and output current. 2.4V input voltage can be boosted to 5V stable output.

2) Charge management module and energy storage: The charge management module uses the TP4057 chip to protect the battery, that is, using the combined action of the rectifier diode and the capacitor, the AC with low voltage amplitude becomes a DC voltage with high voltage. The energy storage is lithium battery.

3.2.3. Boost Chopper Circuit

The schematic diagram and working waveform of Boost Chopper circuit are shown in Figure 6. A fully controlled device is also used in this circuit.

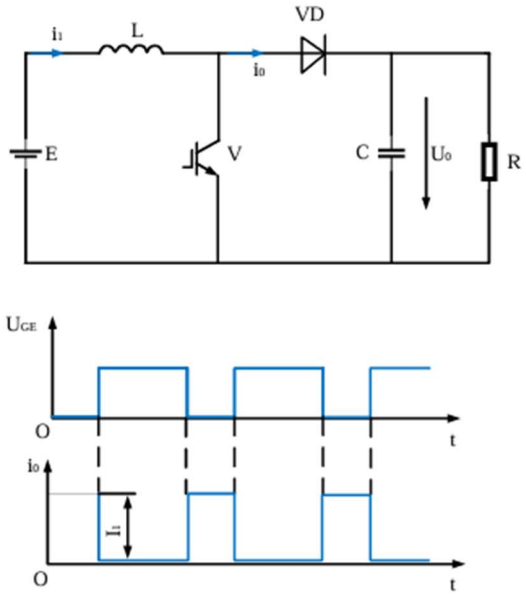

Figure 6. Booster circuit topology and operating waveform

First, assume that the inductor L value in the circuit is large, and the capacitor C value is also large. When the controllable switch V is in the on state, the power supply E charges the inductor L, the charging current is basically constant I_1, and the voltage on the capacitor C supplies power to the load R. Because the value of C is very large, the output voltage u_0 is basically maintained as a constant value, which is denoted as u_0. Let V be in the on-state time t, and the energy accumulated on the inductor L at this stage is EI_1t_{on}. When V is in the off state, E and L jointly charge the capacitor C and provide energy to the load R. Let V be off for t_off, then the energy released by the inductor L during this period is:

$$I_1 t_{on} = (U_0 - E) I_1 t_{off} \tag{1}$$

Simplify to:

$$U_0 = \frac{t_{on}+t_{off}}{t_{off}} E = \frac{T}{t_{off}} E \tag{2}$$

ISSN: 2664-9640

In the formula, $T/t_{off} \geq 1$, the output voltage is higher than the power supply voltage, so the circuit is called the boost chopper circuit.

3.3. Hardware Design

Figure 7 shows the overall hardware design of the booster circuit and battery power control circuit. The actual picture is shown in Figure 8.

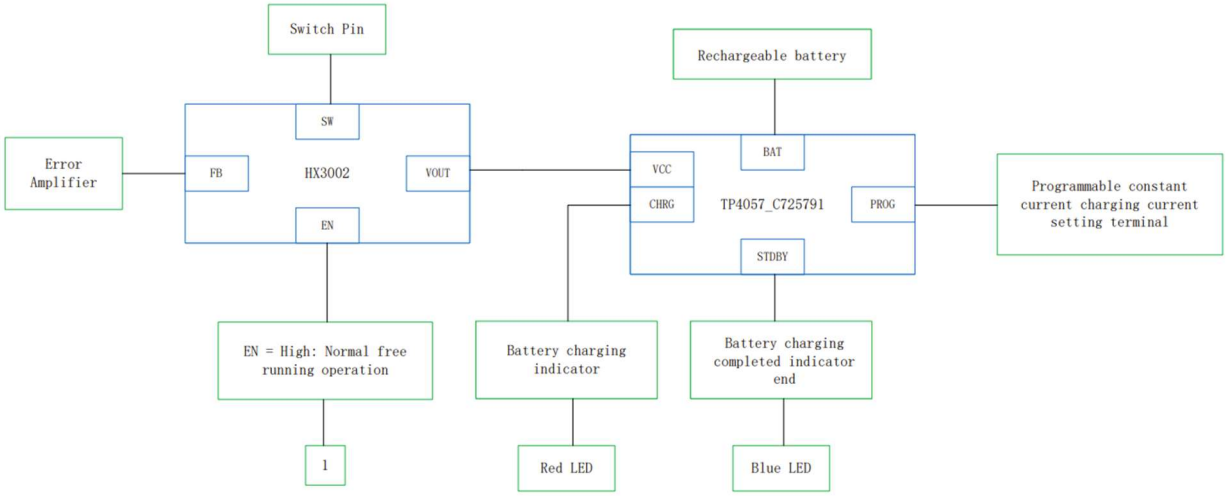

Figure 7 Hardware schematic diagram

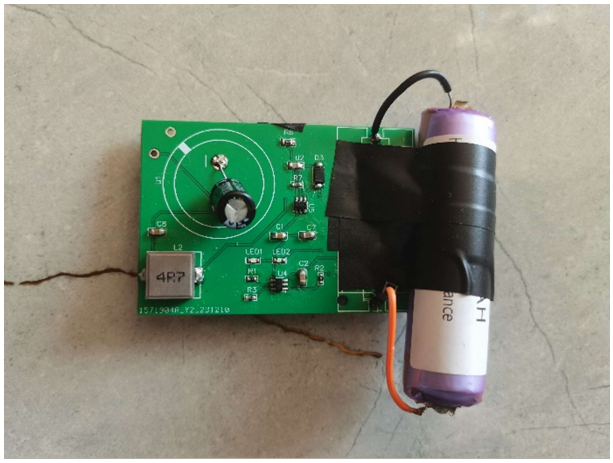

Figure 8 Hardware diagram

1) Each piezo ceramic separate power generation can send out an average 30V AC voltage, as shown in Figure 9, how many V DC voltage after connecting the rectifier bridge, 14 pieces of piezoceramic pieces together, the circuit integration (add load and filter capacitance), can stable output 2.4V voltage. As shown in Figure 10 (the circuit integrates 2.4V voltage).

ISSN: 2664-9640

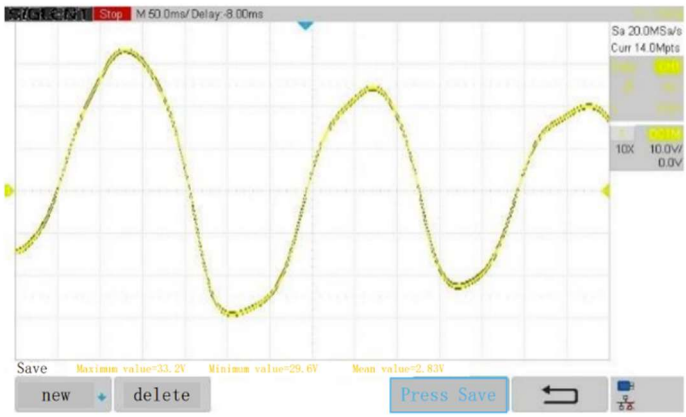

Figure 9 Each ceramic piece generates electricity separately

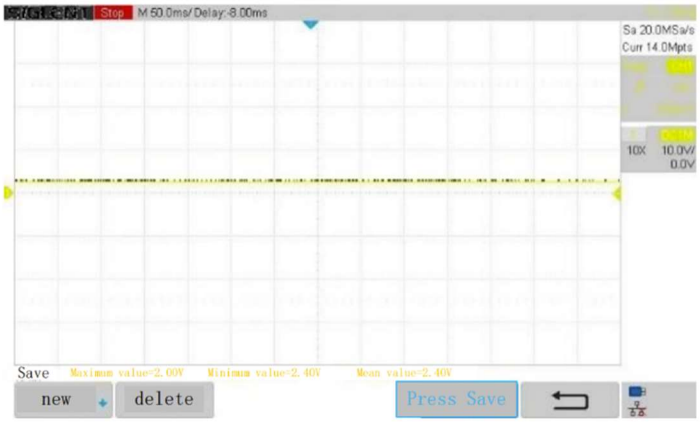

Figure 10: The circuit integrates 2.4V voltage

2) Rectifier bridge: Because the walking power generation can be manually controlled off, the rectifier bridge uses the LB10S chip whose device is a diode.

3) Filter capacitor: After 0~2200UF size capacitor selection, the final selection of 470UF filter capacitor, can be stable and efficient filtering, and fast charging time and output flat direct current. The comparison of waveforms before and after filtering is shown in Figure 11 and Figure 12.

Figure 11 Unfiltered capacitance

ISSN: 2664-9640

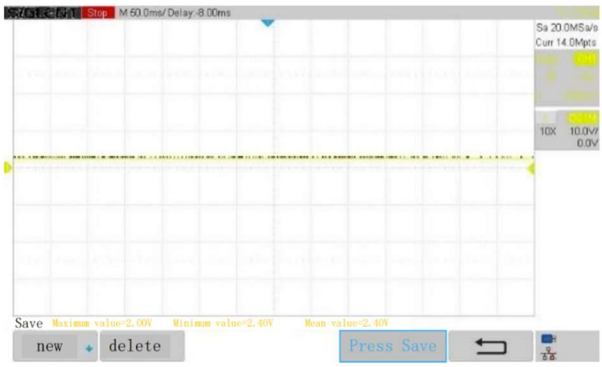

Figure 12 A filter capacitor on load condition

4) Boost circuit: The chip HX3002 is used to increase the input voltage of 2.4V to 5V output.
5) Lithium battery: Choose 18650 lithium battery, rated voltage 3.7V, rated capacity 2000MAH.

3.4. Hardware Modules and Parts Selection

Figure 13 Product drawing (Front and section)

ISSN: 2664-9640

In the experiment, the ceramic pressure generator plate is pressed by simulating human stepping gait, and the power generation situation is recorded by oscilloscope. To control the test conditions, first of all, the test pressing cycle is divided into 3 groups, respectively 2s, 1.5s, 1s, under the condition of constant cycle, change the connection mode of the piezoelectric plate and then divided into 3 groups of control group, respectively, 3 independent, 3 series, 3 parallel three cases. The results show that when other conditions remain unchanged, the maximum output power of the shoes increases with the decrease of the pressing period, which is in line with the expectation. For different connection modes, the same phenomenon is that the output open circuit voltage curve will move down than the previous pulse period due to the existence of RC circuit time constant, and the load output power curve will rise first and then decline. The difference is that the peak of the open circuit voltage curve in series connection is steeper, while the peak of the parallel open circuit voltage curve is flatter.

Finally, the power generation situation of the pressure power shoe is calculated and compared. When the pressing state period is 1s, the output power under the parallel condition is the highest. The main reason is that the equivalent internal resistance after the parallel is smaller, the power consumption is reduced, and the power generation effect is better.

4. Conclusion

Based on energy-saving power generation, make full use of their own energy, develop new energy, learn from the experience of magnetic power generation, the use of multiple piezoelectric ceramic pieces, and the combination of modules such as booster modules, successfully developed environmental protection fitness two mistakes walking and charging wearable devices: pressure power shoes. The requirements of ergonomics and significantly improved power generation efficiency are realized.

5. Innovation Point

This design will walk power into electricity, through the experimental demonstration, this energy-saving power shoes energy conversion efficiency is high, light and comfortable audience wide, high practical value and easy to achieve low cost, has broad application prospects.

Table 1. Be creative and elaborate

Innovation point	Detailed description
Piezoelectric capacity, self-production and self-use	The device is put into the sole to convert the walking power into electricity, and its maximum power can reach 15W per hour, which is enough to charge ordinary laptops or mobile phones, and has the advantages of high energy conversion efficiency, stable voltage charging and small power loss.
Green economy, low carbon environmental protection	According to local conditions and time, the device recyles the mechanical energy of human walking to realize walking and charging, which is in line with low-carbon green travel, civilized and healthy lifestyle, and promotes the creation of a green and low-carbon society.
Humanistic care, integration and innovation	The design of power generation shoes based on piezoelectric ceramics is light and easy to realize. The generated power supplies the GPS positioning system to ensure the safety of the user's travel, and can also charge electronic devices through the USB interface to alleviate "electricity anxiety".

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