Research on Vibration Energy Acquisition Method of Piezoelectric Generator

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Abstract

With the modern weapon system to fuze reliability, security, versatility and storage life and other technical requirements are becoming higher and higher, the traditional chemical battery power supply mode can not meet the requirements of modern weapon fuze power supply. In order to meet the power supply needs of modern fuze, based on the analysis of the electrical characteristics of piezoelectric materials, the vibration energy acquisition method of the fuze piezoelectric generator is studied, and the energy acquisition method of the fuze piezoelectric generator is optimized, so as to achieve the purpose of efficiently collecting the output energy of the piezoelectric generator. The research method in this paper provides a theoretical reference for the research of vibration and piezoelectric energy acquisition technology of piezoelectric generator, and provides a reference for the further research and design of vibration energy acquisition technology.

Keywords

Piezoelectric vibration energy, Energy collection, Power management

1. Introduction

Vibration energy is a common energy of natural environment, which is widely used in military facilities, industrial equipment, human movement and biological activities. Piezoelectric vibration power generation devices are widely used in vibration energy capture because of their advantages such as simple structure, flexible shape, high energy density and easy miniaturization[1-2]. Because of its advantages of simple structure, flexible shape, high energy density and easy to realize miniaturization, piezoelectric vibration generator is widely used in vibration energy capture. However, due to the high capacitive impedance of piezoelectric materials, the output power of the generator has the characteristics of low current and high voltage, and its output power is related to the load. At the same time, because of the characteristics of vibration energy, the output of the piezoelectric generator is AC electric energy, and can not directly charge the battery or power the fuze load equipment. Therefore, a power collecting circuit must be added between the piezoelectric generator and the fuze load equipment, whose function is to realize AC - DC conversion and improve the output power of the piezoelectric generator[3].

2. DC - AC rectifier circuit

Due to the characteristics of vibration energy, the output is AC electric energy, which can not directly charge the battery or power the load. Therefore, AC/DC rectifier circuit should be added between piezoelectric material and load to collect electric energy.

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2.1. Standard energy harvesting circuit

Figure 1 shows the traditional standard energy collection circuit, which is the simplest and most classical full-bridge rectifier circuit. The entire circuit consists of four diodes, with R_0 representing the load.

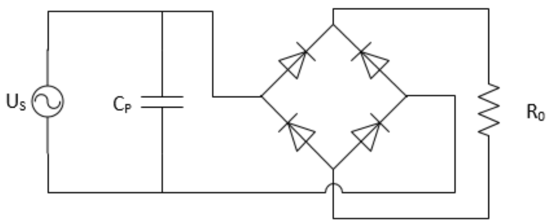

Figure 1: Standard energy harvesting circuit

It is assumed that the electric energy excitation generated by the vibration F of the piezoelectric material is the standard sinusoidal oscillation excitation, defined as

$$V(t) = V_0 \sin(\omega t) \quad (1)$$

In Equation（1）， V_0 is voltage amplitude and ω is vibration frequency. According to Kirchhoff's law and the piezoelectric equation, the voltage on the load resistance R_0 can be obtained as follows:

$$V_R = \frac{\alpha\omega U(R_0 + 2R_D)}{(R_0 + 2R_D)C_P\omega + \frac{\pi}{2}} \quad (2)$$

In Equation（2）， α is electromechanical coupling factor, U is vibration displacement of piezoelectric material, R_0 is load resistance, R_D is rectifier diode loss resistance, C_P is internal static capacitance of piezoelectric material. Then, the average power on the load resistor is:

$$\overline{P_R} = \frac{V_R^2 R_0}{R_0 + 2R_D} = \frac{(R_0 + 2R_D)\alpha^2\omega^2U^2R_0}{\left[(R_0 + 2R_D)C_P\omega + \frac{\pi}{2}\right]^2} \quad (3)$$

Because of the simple structure of standard energy collection circuit, its application field is very wide, but the circuit has the problems of low collection efficiency and high energy loss, and there are many places to be improved.

2.2. MOSFET energy collection circuit

In order to eliminate the problem of high starting voltage and high power consumption caused by a large diode voltage drop, the power MOSFET is used to replace the rectifier and form an active rectifier circuit. The voltage drop of MOSFET is close to zero, and it has approximately the circuit characteristics of ideal diode. Therefore, the power loss and starting voltage of the rectifier circuit can be reduced, and the energy collection efficiency can be improved.

As shown in Figure 2, the voltage comparator is used to cross-couple NMOS and PMOS[4], so that the MOSFET can work in the amplification area, so that it can be completely closed, and improve the energy collection efficiency. The principle is that when the output voltage of piezoelectric material is in a positive half period, because $V_{out} - V_1 > |V_{THP1}|$, At this point, M_{P1} and M_{N2} are on, and M_{P2} and M_{N1} are off. At the end of C_P discharge, when V_1=V_2, all MOSFET cut off. Similarly, when the output voltage of piezoelectric material is in negative half period, due to $V_{out} - V_2 > |V_{THP2}|$, At this point, M_{N1} and M_{P2} are on, and M_{N2} and M_{P1} are off.

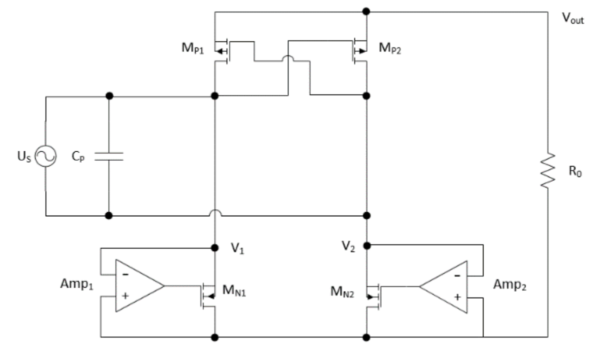

Figure 2: MOSFET energy collection circuit

According to Kirchhoff's law and the piezoelectric equation, the voltage on the load resistance R_0 can be obtained as follows:

$$V_R = \frac{\alpha\omega U R_0}{R_0 C_P \omega + \frac{\pi}{2}} \tag{4}$$

The average power on the load resistor is:

$$\overline{P_R} = \frac{V_R^2}{R_0} = \frac{R_0 \alpha^2 \omega^2 U^2}{(R_0 C_P \omega + \frac{\pi}{2})^2} \tag{5}$$

According to the Equation (5), under the condition of constant vibration displacement U of piezoelectric material, there exists an optimal load resistance and maximum output power:

$$R_{OPT} = \frac{\pi}{2 C_P \omega} \tag{6}$$

$$P_{MAX} = \frac{\omega \alpha^2 U^2}{2\pi C_P} \tag{7}$$

3. Passive power factor correction circuit

After the electric energy output by piezoelectric material passes the rectifier circuit, its voltage waveform is close to the DC circuit, and the current produces distortion and distortion because the conduction time of the rectifier tube is too short, which becomes a spike pulse and reduces the power factor. The passive power factor correction method is to make the input current of the circuit close to sine wave by adding passive components such as capacitance and inductance into the circuit, that is, to improve the power factor through reactive power compensation, so as to achieve the purpose of increasing active power[5]. Compared with other circuits, grain filling circuit needs fewer components and has better performance. The grain filling circuit is shown in Figure 3.

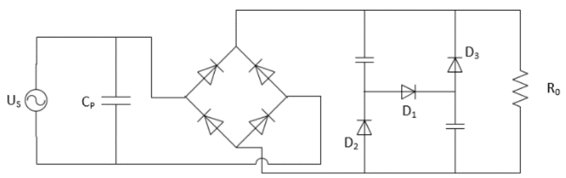

Figure 3: Passive power factor correction circuit

Its working principle: when the capacitor in the filling circuit is charged, the capacitor in the circuit in series to reduce the capacitance value, to achieve the purpose of fast charging; When discharging, the capacitor is in parallel, and the voltage at both ends of the capacitor is 1⁄n of the peak total voltage (n is the order of the capacitor), which reduces the circuit's recharging inch charging voltage threshold.

When the circuit is charging, D_1 in the filling circuit is on, D_2 and D_3 are off, and the two filter capacitors are connected in series. The series of capacitors reduces the total capacitance value and therefore the time constant. When the circuit discharges, D_1 in the filling circuit shuts off, D_2 and D_3 are on, and the two filter capacitors are connected in parallel. The voltage at both ends of each capacitor is 1⁄2 peak voltage, which reduces the charging threshold when the circuit is recharged.

Output power of grain filling circuit is:

$$P = \frac{V_R^2}{R} = \frac{4V_0^2 C_P^2 \omega^2 R}{(2C_P R\omega + \pi)^2} \tag{8}$$

With $\partial P/\partial R = 0$, it can be known that the maximum output power and optimal load resistance of piezoelectric material are:

$$P_{MAX} = \frac{V_0^2 C_P \omega}{2\pi} \tag{9}$$

$$R_{OPT} = \frac{\pi}{2\omega C_P} \tag{10}$$

Valley filling circuit can greatly increase the conduction Angle of rectifier tube, by filling the valley point, the input current from the peak pulse to the waveform close to the sine wave, reduce harmonic content, improve the power factor, significantly reduce waveform distortion.

4. BUCK - BOOST circuit

The waveform of the circuit corrected by the filling circuit is similar to that of the DC power supply. At this time, the output voltage can be adjusted by the buck-Boost circuit to make the output voltage meet the requirements of the load. The circuit is shown in Figure 4.

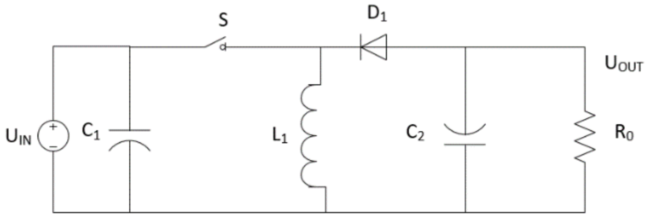

Figure 4: BUCK - BOOST circuit

Its working principle: when the switch S is closed, the inductor L1 is directly connected to both ends of the power supply, and the inductance current gradually rises. The di/dt is very large in the transient state, so the input capacitor C_1 is the main power supply during this process. At the output end, C_2 provides energy for R_0 by its own discharge. When switch S is off, power supply V charges the input capacitor. Since the current of the inductor cannot be mutated, the inductor L_1 supplies power to the output capacitor C_2 and the load R_0 through the continuation tube D_1. After stable operation, the inductance is conserved in volts second. When the switch S is on, the inductance voltage is equal to the input power voltage V_{IN}; When switch S is off, the inductance voltage is equal to the output voltage V_{OUT}. Let T be the cycle, T_{ON} be the on-time, T_{OFF} be the off time, D be the duty cycle.

$$V_{OUT} = \frac{D}{1-D} V_{IN} \tag{11}$$

When duty cycle is less than 0.5, output step-down; When duty cycle is greater than 0.5, output boost.

5. Simulation

The circuit is shown in Figure 5, figure 6 is the simulation of traditional energy collection circuit, and Figure 7 is the simulation of induced piezoelectric energy collection circuit.

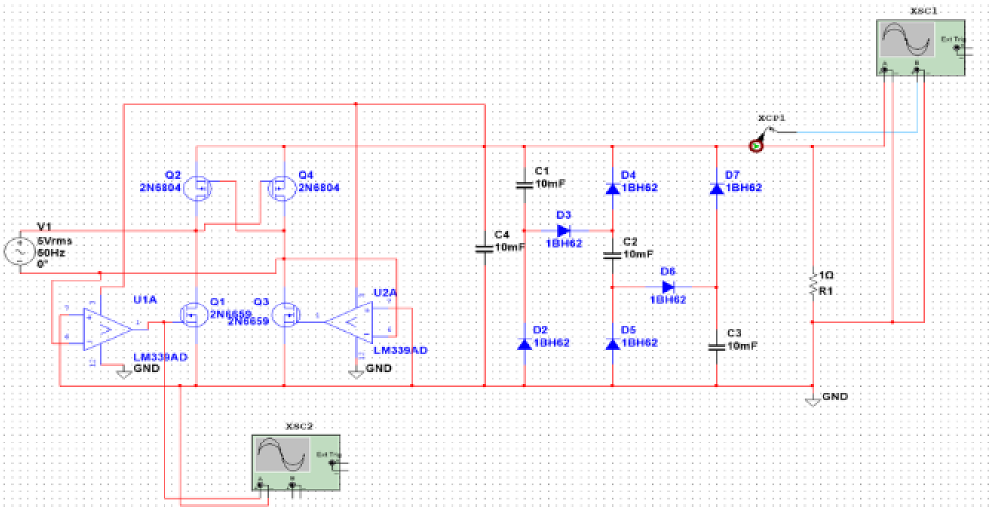

Figure 5: Lead the piezoelectric energy collection circuit

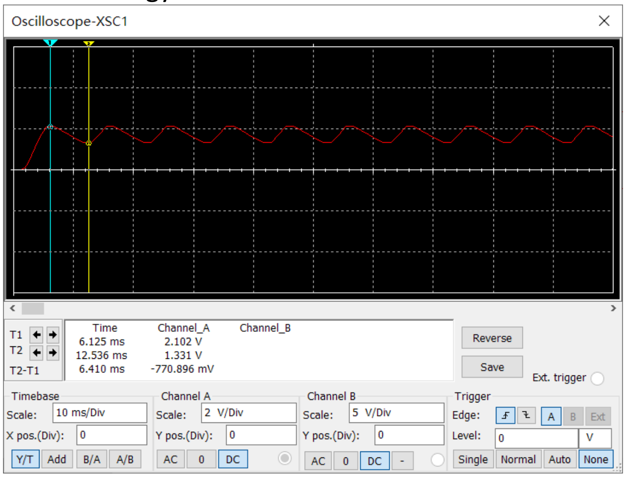

Figure 6: The simulation of traditional energy collection circuit

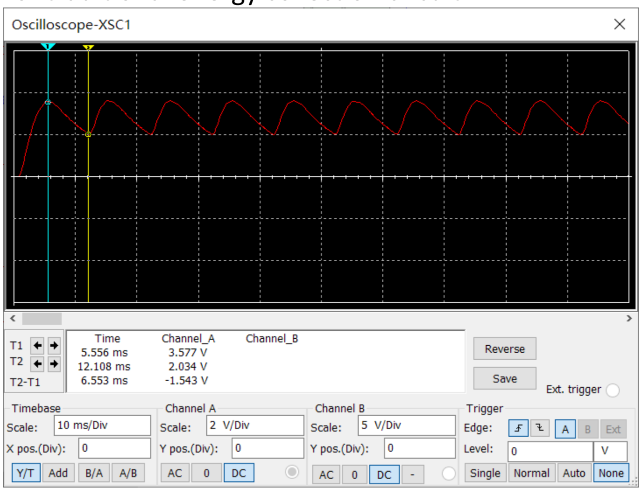

Figure 7: The simulation of lead the piezoelectric energy collection circuit

It is assumed that the voltage amplitude of the input AC voltage source is 5V, and the peak voltage of the traditional energy collection circuit is 2.102V and the valley is 1.331V. After using the new energy collection circuit, the peak voltage is 3.577V and the valley is 2.034V.

6. Conclusion

Comparing the output voltage of the traditional energy collection circuit with that of the induced piezoelectric energy collection circuit, the peak voltage is increased by 1.455 V, the valley value is increased by 0.703 V, the average output voltage is increased by 29.4%, and the energy collection efficiency is improved to a certain extent.

In this paper, a piezoelectric energy collection circuit with low power consumption and high acquisition efficiency is designed, which uses active diode instead of traditional diode to reduce the voltage loss and improve the power conversion efficiency.

7. References

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