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Experiment Research on Power Generation Performance of Double Piezoelectric Vibration Energy Harvester

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Abstract. In order to collect the vibration energy in the environment, the cantilever double piezoelectric vibration energy harvester is designed to collect the mechanical vibration energy of the motor. The output voltage of the upper and lower piezoelectric ceramic wafer of the bimorph piezoelectric vibrator and the output voltage of the cantilever suspension length at different rotational speeds of the motor are investigated. At last the experimental results are verified.

1. Introduction

Mechanical vibration are ubiquitous in the environment, the mechanical vibration energy harvesting environment together into a microelectronic device for low-power electrical energy, take the place of the traditional chemical batteries supply for wireless sensor network node, portable electronic devices MEMS and other low power consumption electronic products [1]. At present, there are many types of vibration energy harvesting technology: piezoelectric, electrostatic, composite, electromagnetic and others [2]. The piezoelectric vibration energy harvester is to convert the mechanical energy of vibration into the electric energy that can be used for low energy consumption electronic products [3].

The piezoelectric vibration energy harvester is usually composed of cantilever piezoelectric bimorph or piezoelectric unimorphs structure, in order to improve the conversion efficiency, the end of the cantilever beam is usually a fixed amount of mass to reduce the energy harvester natural frequency to increase vibration inertial force of the cantilever beam [4]. The vibration energy in the environment is unstable, so the piezoelectric power generator can only transform the vibration energy into smaller electrical energy, the power generated by the mechanical vibration is often difficult to meet the demand of low power consumption for a long time [5]. In order to effectively improve the energy conversion efficiency of the high voltage power generation device, it is necessary to predict, analyze and optimize the parameters of the double piezoelectric vibration energy harvester and bimorph piezoelectric parameters of the cantilever beam [6]. At present, the piezoelectric vibration energy harvester of cantilever beam has been widely studied at home and abroad. In 2015, Hongjun Liu and Dingfang Chen et al. [7, 8] established the electromechanical coupling model of piezoelectric vibration energy harvester, obtained the influence of different geometric dimensions on structural response characteristics and output performance. In 2017, Binqiang Yang, Wentan Xu et al. [9] used Hamilto principle and Raleigh-Ritz method to establish the electromechanical coupling model of the piezoelectric energy harvester, numerically analyzed the influence of the parameters such as the mass ratio, the stiffness ratio and the damping ratio of the energy collector on the vibration characteristics and output characteristics of the system. Cantilever beam piezoelectric vibration energy harvester and bimorph piezoelectric structure parameters are all explored through the establishment of an ideal model.

2.Theoretical analysis

Figure 1 shows the sketch of model of double piezoelectric energy harvester with cantilever beam. Due to the same properties of the two piezoelectric ceramic materials on the bimorph piezoelectric, the upper and lower surfaces of the piezoelectric substrate are respectively pasted on the upper surface of the substrate, the upper and the lower piezoelectric ceramics are symmetrical on the X axis, therefore, the piezoelectric cantilever beam is forced to vibrate together with the vibration source when the mechanical vibration is excited, the piezoelectric cantilever beam will be deformed, and the change in strain and stress in the piezoelectric layer will be the same. For the piezoelectric effect of the bimorph, the open circuit voltage and the electrical energy of the upper and lower piezoelectric ceramic plates are equal, but the open circuit voltage is opposite.

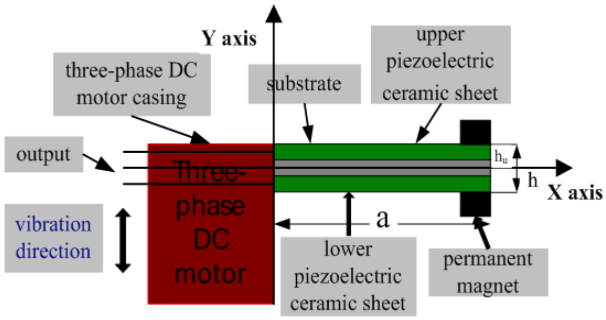

Figure 1. Sketch of model of double piezoelectric vibration energy harvester with cantilever beam.

According to the literature [10], the relation between the charge quantity and the exciting displacement of a single bimorph piezoelectric under the action of external force is deduced:

$$Q = \frac{-3bABg_{31}E_P h^2}{16aAh_u(E_P g_{31}^2 + \beta_{33}^T) - 6haB^2 E_P g_{31}^2}\delta t \tag{1}$$

The capacitance of bimorph piezoelectric vibrator is:

$$C = \frac{8Aab}{8Ah_u(E_p g_{31}^2 + \beta_{33}^T) - 3hB^2 E_P g_{31}^2} \tag{2}$$

where $A = 1-\alpha^3 + \alpha^3\beta$, $B = 1-\alpha^2$, $\beta = E_m / E_p$ δt - the excitation displacement, α - the ratio of the thickness of the metal substrate to the total thickness of the cantilever beam, β - the young's modulus ratio, E_m - the young's modulus of the metal substrate, E_p - the young's modulus of piezoelectric ceramics, g_{31} - the piezoelectric constant.

The power on the load is:

$$P = I^2 \times R = \frac{V^2}{\frac{(R-r)^2}{R} + 4r} \tag{3}$$

3. Experiment

3.1. Experimental principle

The vibration energy structure principle of the double cantilever piezoelectric vibration energy harvester is shown in figure 1, double cantilever piezoelectric vibration energy harvester is composed of a bracket, a bimorph piezoelectric plate and two permanent magnets, the double piezoelectric element operates in the d31 mode. The double piezoelectric ceramic crystals of bimorph piezoelectric bonds adhere to both sides of the elastic substrate to form an electric energy output anode, the surface of the upper and lower piezoelectric ceramic crystal plates respectively constitutes the positive electrode of the upper and lower piezoelectric plates. This paper used the positive piezoelectric effect of piezoelectric ceramics. The cantilever bimorph is fixed on the shell of the three-phase DC motor at one end, the permanent magnet on the free end fixed a certain quality, the piezoelectric cantilever is forced to vibrate in conjunction with the vibration source when the mechanical vibration of the motor generating excitation, the permanent magnet will be affected by the inertial force and occur the piezoelectric cantilever deformation, which will cause the changes of piezoelectric layer strain and stress , there will have a change of potential difference output from a positive and negative electrode on bimorph because of the positive piezoelectric effect between the bimorph.

3.2. Experimental device structures

The double piezoelectric vibration energy harvester is a bimorph piezoelectric cantilever with two piezoelectric ceramic layers. One end of the piezoelectric energy harvester is fixed on the shell of the three-phase synchronous DC motor, and the other end is fixed with a permanent magnet strip of 2g, the motor will produce mechanical vibration when it is running, and the piezoelectric vibration energy harvester will change the mechanical vibration energy of the motor into electrical energy. As shown in figure 2, the AC motor test bench controls the speed (N) of the three-phase synchronous DC motor, the speedometer shows the motor speed N, the oscilloscope measures the waveform and size of the output voltage of the piezoelectric vibration energy harvester. Table 1 is the material parameters of bimorph piezoelectric.

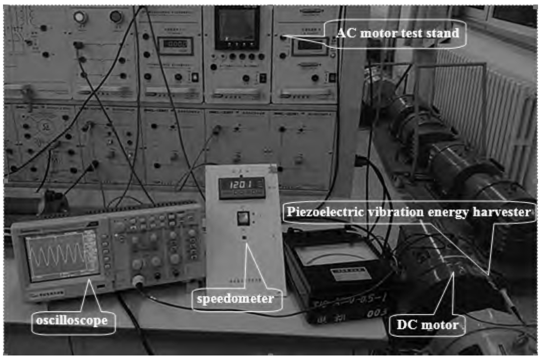

Figure 2. Experimental device diagram.

Table 1. Material parameters of bimorph piezoelectric.

parameters	value
Resonance impedance/oHm	***<70***
Static capacitance/nF	***380--430***
Piezoelectric ceramic materials	***PZT P8-79Y***
Substrate material	***Kover#4J29***
Resonance impedance	***<90 oHm***
Qm	***400***
eT33	***1300***
Kt33	***4500***

4. Experimental results

4.1. Output voltage of upper and lower piezoelectric ceramic wafers

Figure 3 is the output voltage of the upper and lower piezoelectric wafers at different speeds of the motor. It can be seen from the curve that the output voltage of the upper and lower piezoelectric wafers has a maximum peak value with the increase of the motor speed. And both reach the maximum at the motor speed of 1200r/min, the maximum output voltage of the upper piezoelectric wafer can reach 756mv, the maximum output voltage of the lower piezoelectric wafer can reach 728mv. The speed of motors are the same when the upper piezoelectric wafer output voltage is close to lower and reaches the maximum open circuit voltage.

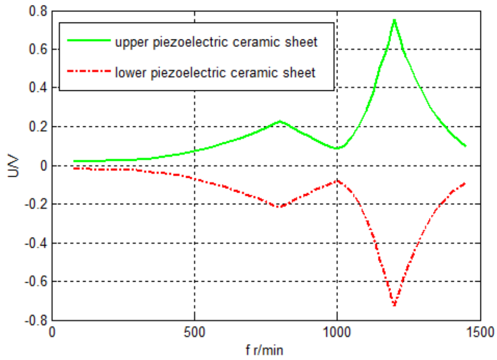

Figure 3. Output voltage of upper and lower piezoelectric bimorph at different speeds.

4.2. Suspension length of cantilever beam piezoelectric bimorph influence on output voltage
Figure 4 is the output voltage diagram of a cantilever beam bimorph with different suspension lengths at different speeds of the electromotor. It can be seen from the figure that the motor speed increases with the cantilever suspension length increasing to reach the maximum output voltage, but the output voltage of the peak size are different, there is a maximum output voltage, the relationship between the maximum output voltage are V4.5 > V4 > V5 > V3.5. In the figure, the maximum output voltage is 801Mv when the cantilever piezoelectric plate is suspended by 4.5cm. The maximum output voltage will decrease when the length of the cantilever beam is increasing or decreasing, however, the speeds of the motor are different when reaching the maximum speed, the speed of the motor increases with the increase of the length, which means, the vibration frequency will increase when the maximum is reached.

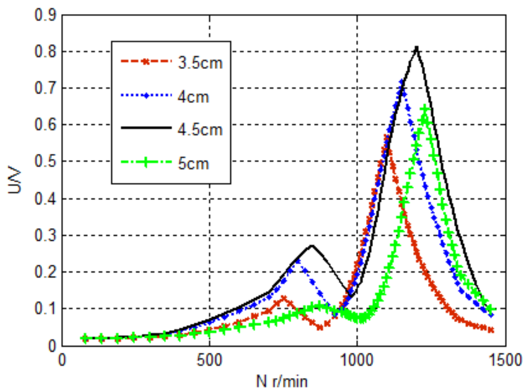

Figure 4. Output voltage of cantilever piezoelectric bimorph under different suspension length when the motor is at different rotational speeds.

5. Conclusions
This paper set up an experimental platform for mechanical vibration energy harvester, the mechanical vibration energy of the motor is converted into electric energy by means of a cantilever beam piezoelectric generator. The output voltage of the upper and lower piezoelectric ceramic wafer of the bimorph piezoelectric vibrator, the output voltage of the cantilever suspension length at different rotational speeds of the motor are investigated. The experimental results show that the upper and lower output voltage of the bimorph piezoelectric are equal, both are sinusoidal AC voltage; the frequency of the mechanical vibration increases with the increase speed of the motor, and there is an optimum suspension length for the bimorph cantilever beam, at which the output voltage is the maximum. Therefore, there is a best paste position on the vibration source of the bimorph piezoelectric cantilever beam to make the double piezoelectric vibration energy harvester get an optimal voltage output

characteristic, which provide a reference for the study of mechanical vibration motor piezoelectric energy harvesting.

6. References

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