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POWER GENERATION CHARACTERISTICS INVESTIGATION OF PIEZOELECTRIC CERAMICS ENERGY HARVESTING CONSTRUCTION

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Abstract. *Vibration is considered one of the most high power and efficient among other ambient energy sources, such as solar energy and temperature difference. Piezoelectric devices are mostly used to convert vibration to ac electric power. The effect of bimorph vibrator type on the power generation was studied in this paper. The no load voltage of bimorph vibrator increased with the increasing of pressure. The bimorph vibrator with less capacitance can produce higher no load voltage.*

Keywords: Piezoelectric ceramics, Bimorph construction, Power generation characteristics

1. **Introduction.** There are many types of energies in human living circumstances. These energies could be natural production, such as solar energy, occurring in the environment. These energies could be artificial manufacturing, such as vibration energy, produced during human walking period. Most part of these energies is dissipated in the natural world and is not utilized. If we can excite these energies and convert them to useful electrical energy they will reduce the demand request of petroleum and coal and thus decrease the emission of carbon dioxide and moderate the environmental destruction furthermore. Renewable energy is generally defined as energy that is collected from resources which are naturally replenished on a human timescale, such as solar energy and wind energy. The large magnitude of solar energy and wind energy available makes it a highly appealing commercial source of electricity. Compared with solar energy and wind energy, vibration energy, to gather the vibration energy is seldom noticed. However, the vibration energy is the most existence in human living environment, such as human walking and machine operating. However, gathering the vibration energy has the advantage of without the limit of environment and weather. Therefore, we call it as "energy harvesting".

The energy harvester devices are capable of capturing environmental energy and supplanting the battery in a standalone module, or working along with the battery to extend substantially its life. Vibration is considered one of the most high power and efficient among other ambient energy sources.

A number of research papers have been dedicated to energy harvester device development and associated with electronics for different forms of vibration-to-electrical energy conversion. Shenck and Paradiso in 2001 [1] at the MIT Media Laboratory presented a pioneer energy-scavenger unit that constitutes an essential part of an RFID tag for direct charging. Ng and Liao in 2004 and 2005 [2,3] also developed a piezoelectric energy harvest system which includes a power circuit to collect the low-level energy extracted from the piezoelectric device for communication systems for direct charging.

They can be classified by different mechanisms of transduction: (1) piezoelectric; (2) electromagnetic; and (3) electrostatic harvesters. Piezoelectric devices are mostly used to convert vibration to ac electric power [1-6]. The effect of two bimorph vibrator types on the power generation was presented in this paper. The prototype of two type structures are fabricated, tested and then compared. The rest of this paper is organized as follows. Experimental procedure is discussed in Section 2. In Section 3, result and discussion are described. Finally, conclusions are presented in Section 4.

2. **Experimental Procedure.** At standard ambient temperature and pressure (SATP), the experimental circuit consists of a piezoelectric device, a rectifier diode, a bucket capacitor, and a voltage monitoring circuit block to drive a load. The piezoelectric ceramics were supplied by Eleceram Technology Co., Ltd., Taiwan. Taiwanese bimorph is using sheet metal to be the support. Characteristics of piezoelectric ceramics are depicted in the following. Dielectric constant coefficient $\left(\varepsilon_{33}^{T}\right) = 2100$, Dielectric loss $(\tan\delta) = 1.5$, a Curie temperature $(T_C) = 325°$, the longitudinal electromechanical factor $(k_{33}) = 0.72$, transverse electromechanical coupling factor $(k_{31}) = 0.32$, piezoelectric charge constant $(d_{33}) = 470 \times 10^{-12}$m/V, piezoelectric charge constant $(d_{31}) = -230 \times 10^{-12}$m/V, a bulk density $(\rho) = 7.9$g/cm^3, and mechanical quality factor $(Q_m) = 65$. The size of piezoelectric ceramics is $40 \times 10 \times 0.2$mm. The bimorph metal sheet is the alloy of 42Ni-Fe. The size is $45 \times 10 \times 0.1$mm. Shown in Figure 1, there are two types of circuits: (a) a series circuit, and (b) a parallel circuit, separately.

The size of piezoelectric sheet is $40 \times 10 \times 0.1$mm, and to compose as bimorph constructions. The size of bimorph is $45 \times 10 \times 0.1$mm. There are two composition styles. Shown in Figure 1, one is $+ - -+$ (the parallel circuit), the other is $+ - +-$ (the series circuit), respectively.

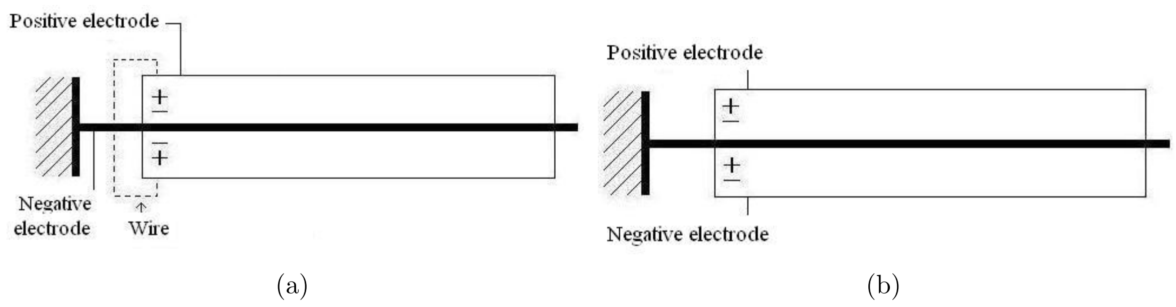

Figure 1. The bimorph metal sheet structure, (a) a parallel circuit and (b) a series circuit

Firstly, we use impedance analyzer to measure the capacitor value of bimorph construction during 1kHz. Secondly, we place the bimorph sheets at the windmill in Figure 2. The windmill rotation speed is from 100rpm to 300rpm to toggle the bimorph sheets. We use FLUKE 287 True-rms Digital Multimeter to measure the no-load bimorph output voltage, current, and power. We also record the above values in adding load conditions after rectifiers. According to the values, we could investigate the relationships of power generation characteristics with the parameters of rectifier circuit, the components connection styles, and the windmill speed. In addition to open circuit voltage, we also analyze the load resistance effect for the output of bimorph sheets. There are four load resistors in

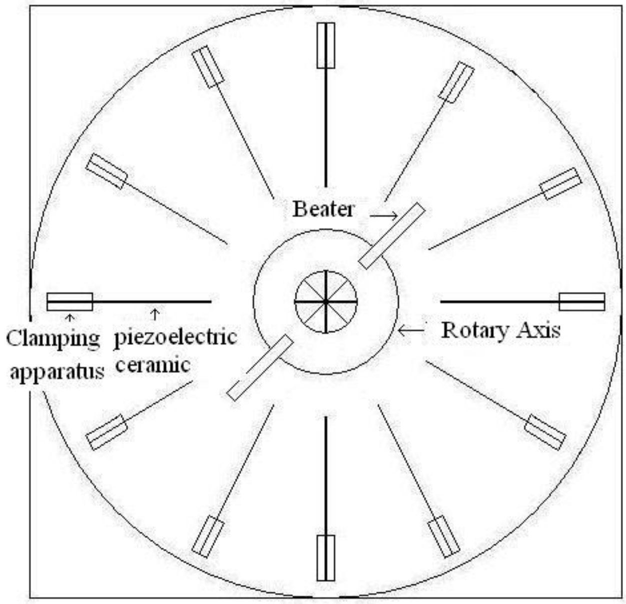

Figure 2. The windmill construction in the paper

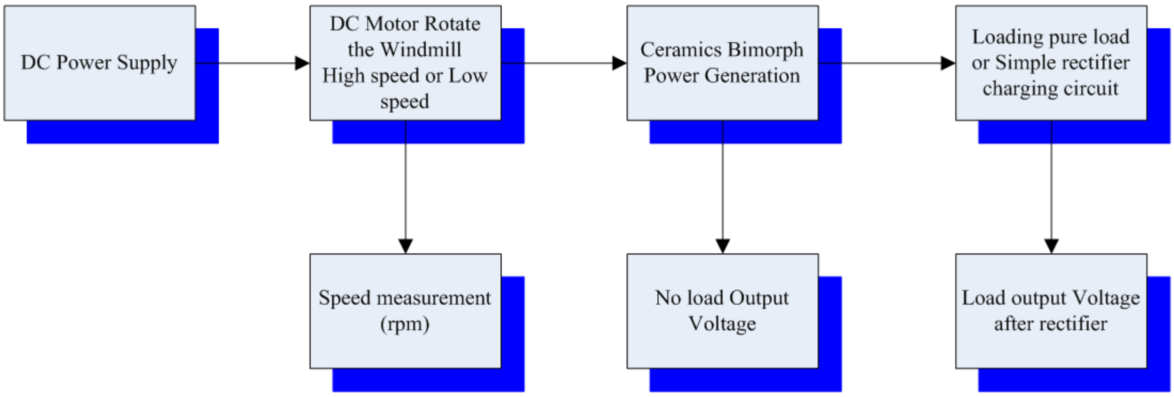

Figure 3. The schematic of experiment method construction

Table 1. The relationship of output voltage and windmill speed during no load in different composition styles of bimorph

Bimorph composition	KA+ − +− (Series circuit)	KA+ − −+ (Parallel circuit)
100rpm	2.9V	2.5V
150rpm	3.7V	3V
200rpm	4.6V	3.3V
250rpm	6.3V	4V
300rpm	7.6V	4.5V
350rpm	8.8V	5.8V

this paper. Those resistors are 100Ω, 1kΩ, 1MΩ, and 10MΩ, respectively. The schematic of experiment method construction is shown in Figure 3.

3. **Result and Discussion.** Shown in Table 1 and Figure 4 there is the relationship of output voltage and windmill speed (rpm) during no load in different composition styles of bimorph. We can find the produced output voltage increase in accordance with the

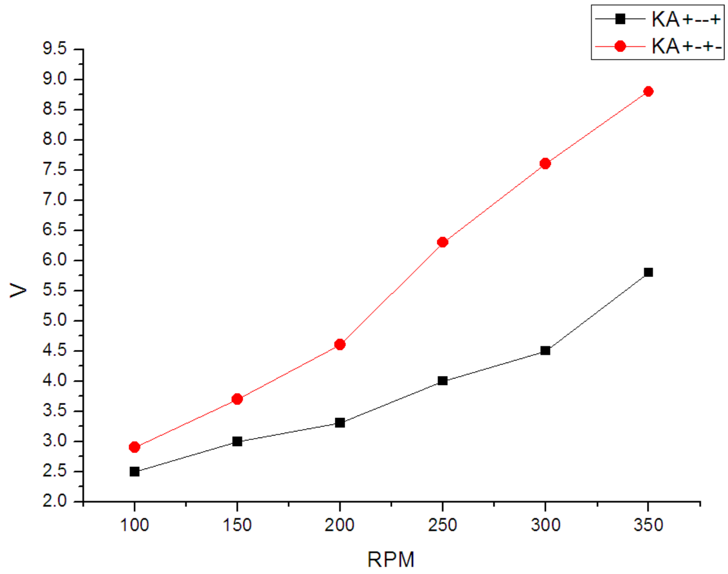

FIGURE 4. The relationship of output open-circuit voltage and windmill speed

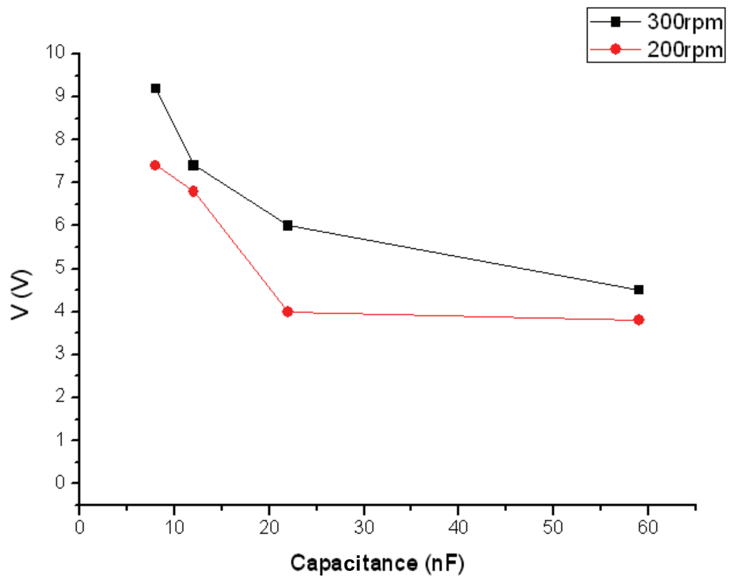

FIGURE 5. The relationship of the no-load output voltage and the composition capacitance

TABLE 2. The comparisons of different load and speed in the series circuit structure

Load / rpm	100Ω	1kΩ	1MΩ	10MΩ
rpm150	1.2μA	1μA	0.3μA	0.1μA
rpm250	2.3μA	1.6μA	0.45μA	0.15μA
rpm350	3.3μA	2.5μA	0.65μA	0.18μA

speed (rpm) of windmill in any composition. This mainly shows the more windmill rpm is, the more acting force on bimorph is. We also find the output voltage of $+-+-$ composition in no load is more than the $+--+$ ones. It may be as the relationship with the composition capacitance. From the experiment results we can know: the less composition capacitance is, the more no-load output voltage is in Figure 5.

Shown in Table 2 and Figure 6 there is the relationship of output current and different load resistors in different windmill speeds. Table 2 and Figure 6 show the relationship of

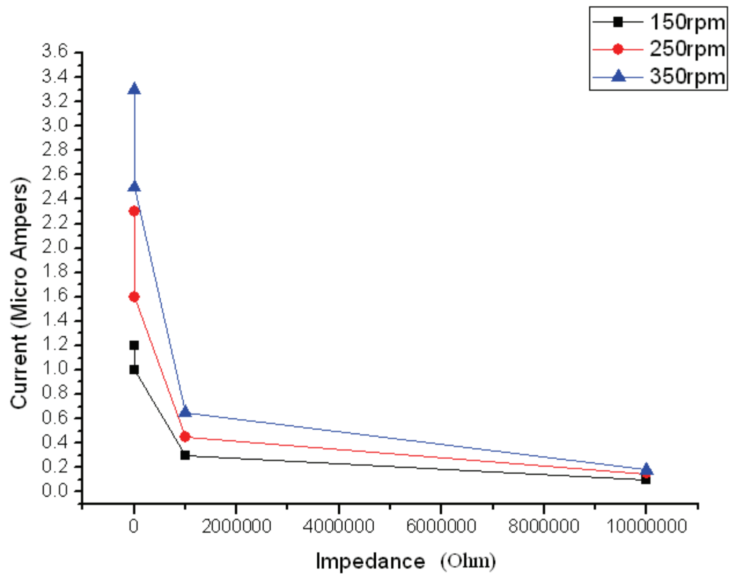

FIGURE 6. The relationship of the load resistors and the currents in the series circuit structures

TABLE 3. The comparisons of different load and speed in the parallel circuit structure

Load / rpm	100Ω	1kΩ	1MΩ	10MΩ
rpm150	1.1μA	0.8μA	0.1μA	0.05μA
rpm250	1.6μA	1.1μA	0.2μA	0.1μA
rpm350	2μA	1.3μA	0.4μA	0.15μA

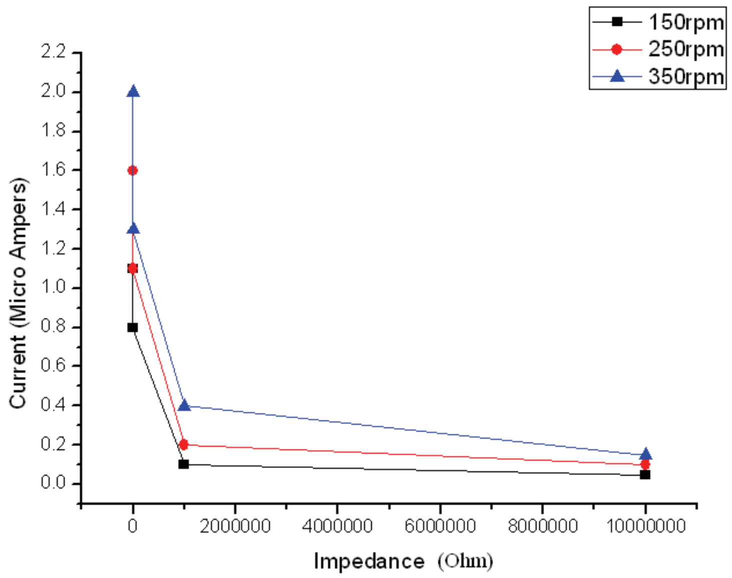

FIGURE 7. The relationship of the load resistors and the currents in the parallel circuit structures

the series circuit (+ − +−) composition. Table 3 and Figure 7 show the relationship of the parallel circuit (+ − −+) composition. From the results of above figures we can know: the more windmill speed is, the more output current is. However, the more load resistor is, the less current is. The series structure produces more current than the parallel circuit structure.

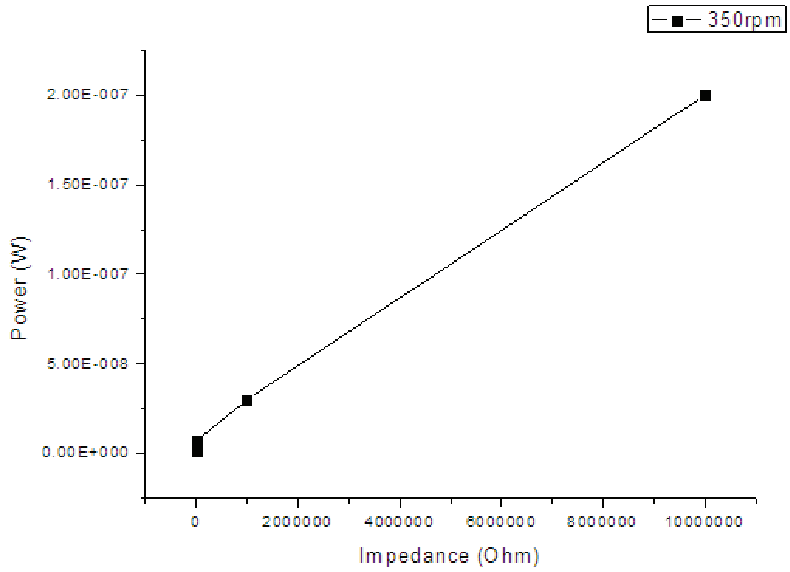

FIGURE 8. The relationship of output power and different load resistors in 350rpm speed

From the above results, the series structure produces the more output power in the higher speed. Shown in Figure 8, there is the relationship of output power and different load resistors in 350 rpm speed. From the results of above figures we can know: the more load is, the more output power is. However, the more load resistor is, the less current is. Therefore, we must carefully choose the load resistor to obtain appropriate current and power in practical application.

4. **Conclusions.** From the results in this paper, we can obtain the conclusions as follows.
(1) The produced output voltage increases in accordance with the speed (rpm) of windmill in any composition style of bimorph. This mainly shows the more windmill speed (rpm) is, the more acting force on bimorph is.
(2) The less bimorph composition capacitance is, the more no-load output voltage is in the higher windmill speed.

Up to now, there has been a continuous effort from the part of some pioneer harvester companies to persuade consumers that the energy harvester will be a "should" solution, and even more so when miniaturization on the sensor module and longer-life spans are both vitally required in the near future.

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