Vibration and Electrical Responses of a Modified Piezoelectric Cantilever Beam with the Unbalanced Spinning Cup

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Abstract

Vibration and electrical response of a cantilever beam attached with piezoelectric discs at the fixed end and an unbalanced spinning cup at the free end studied in this research. This device makes use of wind energy to generate electrical energy via the piezoelectric discs which are attached on the beam. When the unbalanced spinning cups rotated, the beam is stimulated to vibrate and that vibration energy is converted to the electrical energy by the piezoelectric discs. The vibration frequencies of the cantilever beam depend on the angular velocity of the unbalanced spinning cups. The electrical voltage output of the piezoelectric discs also depends on frequency of the beam. In this study, the finite element software, COMSOL, is used to analyze the vibration response of the beam and the electrical voltage output of the piezoelectric discs, and compared these results with the experimental data.

Keywords: Piezoelectric material, vibration, energy harvesting.

1. Introduction

Since the Pierre Curie and Jacques Curie have found that the piezoelectric material can generate electrical charges by mechanical excitation in 1880, the piezoelectric energy harvesting technique is investigated and developed to be prototypes in many forms such as footwear[1], eel[2], wind turbine[3], and etc. The applications of devices are used as a power supply[4] for microelectronics devices or recharging battery[5]. There are many energy sources in the environment that are available to harvest. However, the energy harvesting devices must be designed suitably.

Since the wind source is found commonly in the environment, the wide energy harvesting is an alternative way to generate electrical power for microelectronic devices using at devoid electrical power area. In this work, the design concept of the energy harvesting device is to use wind and vibration sources for generating electrical energy. The studied device consists of a spinning cup and a cantilever beam attached piezoelectric discs. A one of the spinning cups has addition unbalanced mass. It works as vibration generating source when it is blown to rotate by the wind, and caused the cantilever beam vibrated.

In this study, the beam vibration amplitude and the electrical voltage from the piezoelectric discs are studied when the beam is vibrated. The data of voltage output and beam displacement are compared between the finite element and experimental results.

2. Experimental setup & simulation model

2.1 Experimental setup

The cantilever beam is made of stainless steel and the dimension of the beam is 3.1×91×0.125 cm^3 (width×length×thickness). The unbalanced spinning cups are installed at the end of the beam as shown in "Fig. 1". One of the spinning cups has additional unbalance weight of 25 grams. The spinning cups are rotated when the air flew to the cups, causing the beam to vibrate at the same time. The cantilever beam is stimulated to vibrate by the moment loading of centrifugal force when the unbalanced spinning cups rotated. The excitation force amplitude depends on the angular velocity of the unbalanced spinning cups and the excitation frequency on the beam also depends on that angular velocity [6]. The excitation force is given by

$$F = me\omega^2 \qquad (1)$$

where F [N] is the excitation force;
m [kg] is the unbalanced mass;
e [m] is the distance between unbalanced mass and center of rotation;
ω [rad/s] is the angular velocity.

As shown in "Fig. 1 – 2", the experimental setup consists of a cantilever beam attached with the unbalanced spinning cups, an energy harvesting circuit, an air blower, an ultrasonic distance sensor, and an oscilloscope. In the testing, the air blower is set 30 cm beside of the cantilever beam. The wind speed is controlled by an electronic switch to adjust the air blower speed. The angular velocity of the cups is measured by a photo tachometer. When the cantilever beam is vibrating, the ultrasonic distance sensor collects the beam displacement and the oscilloscope collects the electrical voltage output of the piezoelectric discs and energy harvesting circuit. All data is fed to a computer for later analysis and compared with the finite elements.

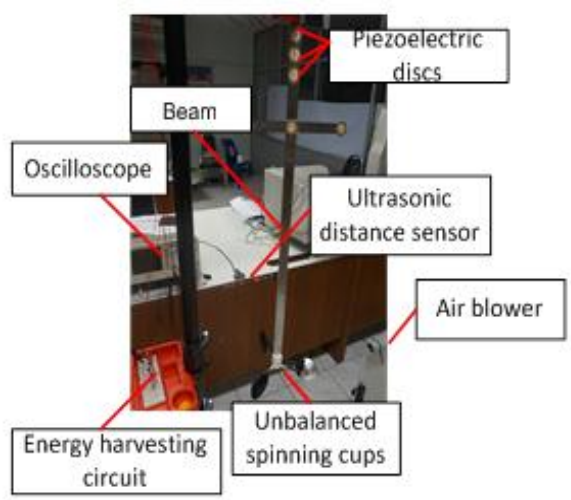

Fig. 1 The modified cantilever beam with the unbalanced spinning cups.

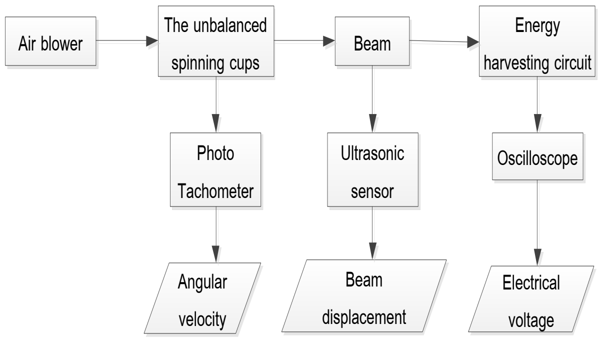

Fig.2 Schematic diagram of experimental setup.

"Fig. 3" shows a schematic diagram of the energy harvesting circuit. This circuit consists of bridge rectifiers and a 0.05 μF capacitor. The six piezoelectric discs are attached at the fix end of the beam. There are three discs per side. Each piezoelectric disc connects to a separate bridge rectifier circuit to harvest the energy with good efficiency [7].

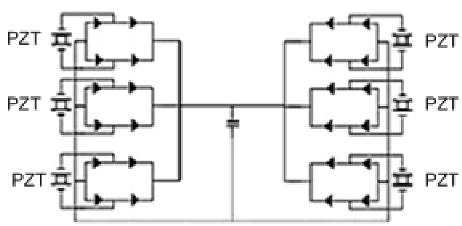

Fig. 3 Schematic diagram of the energy harvesting circuit.

2.2 Simulation model

The finite element (FE) software, COMSOL, is used to simulate the modified cantilever beam characteristics. The FE model is shown in "Fig 4". The model is based on the experimental setup; however, the unbalanced spinning cup is substituted by an equivalent mass at the free end of the beam. There are two analyses in this study. First is to find the natural frequency of beam. Second is to simulate the harmonic response of the system on various frequencies of the excitation force by investigating the beam displacement and voltage output of the piezoelectric discs.

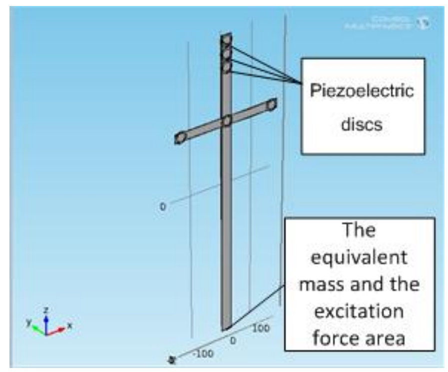

Fig. 4 The FE model of piezoelectric beam.

3. Results & Discussion

In the testing, the vibration frequency range is set between 0-5.97 Hz closing to the fundamental natural frequency and the second natural frequency of the beam. Too high wind speed causes large vibration displacement of the beam, and the unbalanced spinning cups cannot maintain steady angular velocity because the cup rotation plane are out off the wind direction.

Table. 1 shows the natural frequencies at the 1^{st} and 2^{nd} modes of the piezoelectric beam. At the 1^{st} mode, the natural frequency of experimental and FE results are very close.

The difference is noticed in the 2^{nd} mode. This may cause by the reason of system unsteady as mentioned previously. In the FE model, the excitation force is based on "Eq. (1)". Therefore, it still maintains linearity for the whole range of excitation frequency. However, in the experiment at above 4 Hz, the beam vibrates with very large displacement causing the inconsistency of the excitation force.

	Natural Frequencies	
Mode	Experiment (Hz)	Finite element (Hz)
1	0.87	0.97
2	5.45	6.18

Table. 1 Natural frequencies at the 1st and 2nd mode.

The harmonic responses of the beam for the experiment and FE simulation with the damping factor of 0.3 are shown in "Fig. 5". At the steady state, the beam frequency is equal to the excitation frequency of the unbalanced spinning cup. The experimental results of the vibration amplitude of the beam of the 1st mode (0.87 Hz) and the 2nd mode (5.45) are 7.24 cm and 4.0 cm, respectively. The FE results of the vibration amplitudes of the 1st mode (1.1 Hz) and 2nd mode (7.0 Hz) are 7.4 cm and 3.39 cm, respectively.

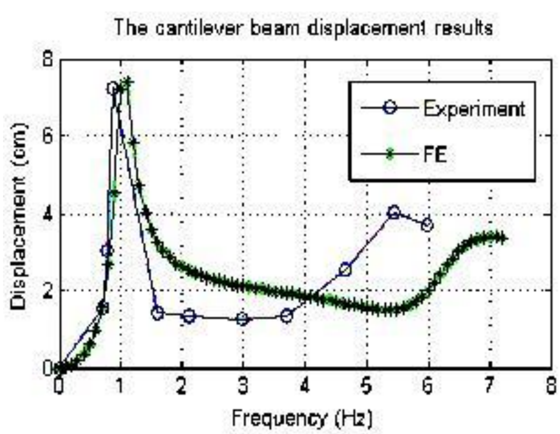

Fig. 5 Vibration amplitude of the piezoelectric beam.

"Fig. 6" shows the electrical voltage output resulting from the piezoelectric discs. In this experiment, the voltage output is measured at the piezoelectric disc and at the energy harvesting circuit. For the 1st mode, the experimental results of the piezoelectric disc and the harvesting circuit are 8V and 7.4V, respectively. The FE result of the piezoelectric disc output is 15.9V. For the 2nd mode, the experiment of the piezoelectric disc and the harvesting circuit are 37.6V and 27.9V, while the FE result of the piezoelectric disc output is 43.5V.

The voltage output of the circuit is less than that of the piezoelectric disc because the voltage loss at the bridge rectifier circuit and the voltage is ripped by the capacitor.

Although the voltage output at the 2nd mode is more than that of the 1st mode, the system response of the 2nd mode is not stable because the beam support and the unbalance spinning cups would have a chance to break down by fatigue load of vibration, and the wind must be kept up to high speed all the time, rarely seen in natural. If the system could be redesigned to have strong support and unbalanced spinning cups, the length of the beam should be extended longer to vibrate at the 2nd mode with the lower wind speed.

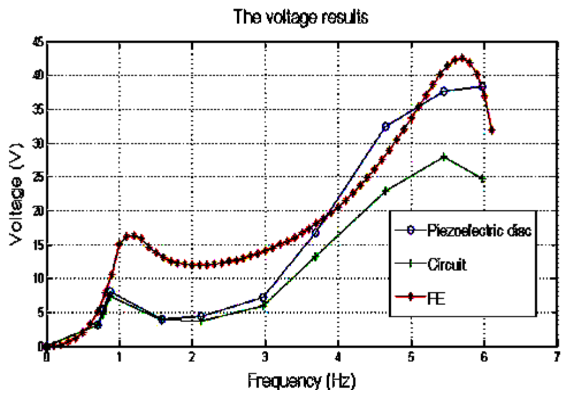

Fig. 6 Electrical voltage output

4. Conclusion

In the experiment, the electrical voltage output of the 1st mode (7.4V) is sufficient for supplying microelectronic devices or recharging a small battery. The experimental and FE results have reasonable agreement and trend which further can be used for designing the length of the beam to suit a specific wind speed. Moreover, it is recommended to design the system that work with the 1st mode vibration for good harvesting efficiency at low natural wind speed.

5. Acknowledgement

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6. References

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