Experimental Study on a Piezoelectric Wind Energy Harvester

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Abstract—To achieve a fluid energy recovery by piezoelectric generator, a piezoelectric wind energy harvester (PWEH) is presented and investigated experimentally. Making use of the force generated by the flow of wind to vibrate the piezoelectric material, the mechanical energy harvested from the vibration of the piezoelectric material is converted into electrical energy. The testing results show that when the end of piezoelectric vibrator isn't added a proof mass and the wind speed is constant, the maximum peak voltage appears between the excited angle of 30 °to 45 °. When the excited angle is greater than 45 °, the voltage is gradually decreases as the excited angle increases. In the case of constant angle, the generated voltage rises with the wind speed increased within a certain range. Adding a proof mass at the end of the piezoelectric vibrator makes voltage produced by the PWEH increase observably. When wind speed, excited angle and the weight of proof mass meet a appropriate matching, the excited frequency of piezoelectric vibrator and natural frequency is equal, the PWEH achieves resonance condition, and the generating performance of the PWEH is optimum.

Keywords-wind energy; piezoelectric vibrator; harvester

I. INTRODUCTION

With the development of the portable electronics and wireless sensors, energy harvesting is becoming a very attractive technique for a wide variety of self-powered micro-electro-mechanical systems (MEMS). In order to satisfy the self-powering demands of micro-power electronics in different fields, the scholars have successfully developed various kinds of piezoelectric energy generators and the vibration generators [1,2] and the rotary generators [3,4]. At present, domestic and foreign research institute research micro-generator about wind energy transformed into electrical energy is still relatively little. MEMS based on micro wind generator even more uncommon. The current point of view from published papers, micro wind generator can be roughly divided into two categories: (1) micro-wind turbine generators[5], the airflow generated by wind power drives turbine rotating, converts the fluidic energy to the mechanical energy using a turbine rotating, then converts mechanical energy into electrical energy output by using piezoelectric transducer or the mechanism of electromagnetic conversion. (2) micro-wind-induced vibration of a wind generator[6], the airflow generated by the wind is transformed into mechanical structural vibration, vibration energy is collected by the method (piezoelectric, electromagnetic, electrostatic, etc.) to achieve the energy conversion.

For airflow energy harvesting, the most common and widely used devices are wind turbines. Although most wind turbine generators are used in large-scale applications, some researchers have designed wind turbines in smaller scales. Holmes et al [7] from Imperial College have reported some micro wind turbines with electromagnetic generators, of which the rotor area is down to approximately 1.5 cm^2. An output power of 4.3 mW at average flow speed of 10 m/s is achieved. Priya et al [8] have combined small windmills with piezoelectric material for energy harvesting and managed to achieve a 5mW continuous power at flow speed of 4.5 m/s.

In order to maximize the energy extraction from translational fluidic energy, influences of physical characteristics of piezoelectric energy harvesters need to be analyzed carefully to get the optimal configuration. A piezoelectric wind energy harvester is designed, and the influence of wind speed, excited angle and the weight of proof mass on energy generation of the PWEH is investigated experimentally to meet the appropriate matching.

II. STRUCTURE AND WORK PRINCIPLE OF THE PIEZOELECTRIC WIND ENERGY HARVESTER

The presented PWEH (as shown in Figure 1) consists of a piezoelectric vibrator, a proof mass fixed on the vibrator end, plywood, support plate, protractor and other components. The piezoelectric vibrator consists of substrate plate and a PZT plate bonded on it, the vibrator is fixed on the plywood. When wind blows the piezoelectric vibrator steadily on the PWEH, the piezoelectric vibrator subjects to the action of airflow, due to the deformation force, each force component of the vertical is clearly different from the direction of the piezoelectric vibrator, since the change of the force, the vibrator deforms continuously (continued self-excited vibration) and voltage is generated. In this way, making use of the force generated by the flow of wind to vibrate the piezoelectric material, the mechanical energy harvested from the vibration of the piezoelectric material is converted into electrical energy.

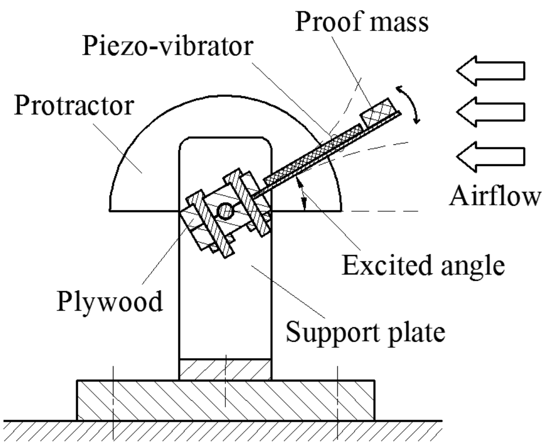

Figure 1. Structure of piezoelectric wind energy harvester

For the wind force is used to excite the piezo-beam, the proposed wind energy harvester has advantages of no impacts and noises in the work process. At the same time, it is easy for the exciting force to be adjusted with changing angle of the piezo-vibrator or distance between the piezo-vibrator and tuyere. Theoretically, the wind energy harvester is able to generate effectively electrical energy in a variety of wind speeds. When the force between the wind and piezo-vibrator is given, the open-circuit voltage and power generated by the piezo-beam can be given as [9,10]

$$V_g = -\frac{3\alpha(1-\alpha)\beta g_{31} L}{\lambda_1 W h} F \quad (1)$$

$$U_g = \frac{1}{2} C_f V_g^{\,2} \quad (2)$$

Where

$\lambda_1 = \alpha^4(1-\beta)^2 - 2\alpha(2\alpha^2 - 3\alpha + 2)\,x(1-\beta) + 1$,

$\lambda_2 = \lambda_1(1-\alpha+\alpha\beta)(1+k_{31}^2) - 3\alpha^2\,x(1-\alpha)\beta^2 k_{31}^2$,

$C_f = \dfrac{(1-\alpha+\alpha\beta)\lambda_1 WL}{(1-\alpha)\beta_{33}^T \lambda_2 h}$ is the free capacitance of piezo-beam, L/W/h are the length/width/thickness of the piezo-beam respectively, $\alpha = h_m / h$ is the thickness ratio, h_m is the thickness of the metal substrate, g_{31} is the piezoelectric voltage constant, $\beta = E_m / E_p$ is the Young's modulus ratio, E_p and E_m are the Young's modulus of piezoelectric and substrate element respectively, $k_{31}^2 = E_p g_{31}^2 / \beta_{33}^T$, $\beta_{33}^T = 1/\varepsilon_{33}^T$ is the dielectric isolation rate, $\varepsilon_{33}^T = 1330\varepsilon_0$ is the dielectric constant of the piezoelectric ceramic in the thickness direction, F is the exciting wind force.

Wind energy is generally calculated by the wind speed:

$$E = \frac{1}{2} m v^2 \quad (3)$$

$$m = \rho A v \Delta t \quad (4)$$

Where E is the energy of the wind, m is the total air mass of a certain volume, v is the instantaneous wind speed, ρ is the density of air, A is the cross sectional area of the air, the amount of m is substituted into the formula E can be obtained wind power [11]:

$$P_T = \frac{1}{2} C_P A \rho v^3 \quad (5)$$

Cp is called energy coefficient, is the general term of some other factor effecting. From equation, wind energy is proportional to the size of the cross-sectional area of the devices inlet, and is inversely proportional to the cubic wind speed, which can be seen, wind speed is an important factor affecting the wind energy.

III. EXPERIMENT AND ANALYSIS

In order to get the relationship of the output frequency and the output of the wind speed, a wind speed test system is fabricated and tested (shown in Figure 2). To verify the feasibility of the presented PWEH, and obtain the effects of related factors on its performance of power generation , an experimental prototype is fabricated and tested (shown in Figure 3). The main test equipment include mainly an AC blower (maximum wind pressure is 1000Mp, air volume of 14m3/min), a frequency converter (the range of adjustment is 0-50Hz, FM step 0.1Hz), an oscilloscope and an anemometer. The piezoelectric vibrator measures 70x20x0.5mm^3, the proof mass is ø12x4mm^3 and 4.37g. The straight distance from prototype to tuyere is defined 17 mm.

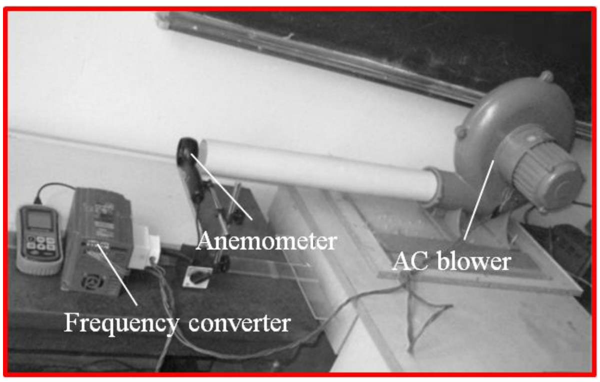

Figure 2. Photo of the wind speed test system

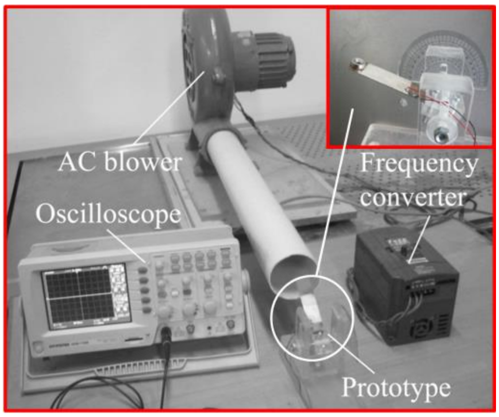

Figure 3. Photo of the PWEH and test system

Figure 4 (a) shows that the relationship of the wind speed and output frequency is proportional. Figure 4 (b) shows the wind speed is a linear decline as the straight distance from tuyere to prototype increases. To increase the output voltage of the prototype, the straight distance from prototype to tuyere is defined 17mm when the performance tests.

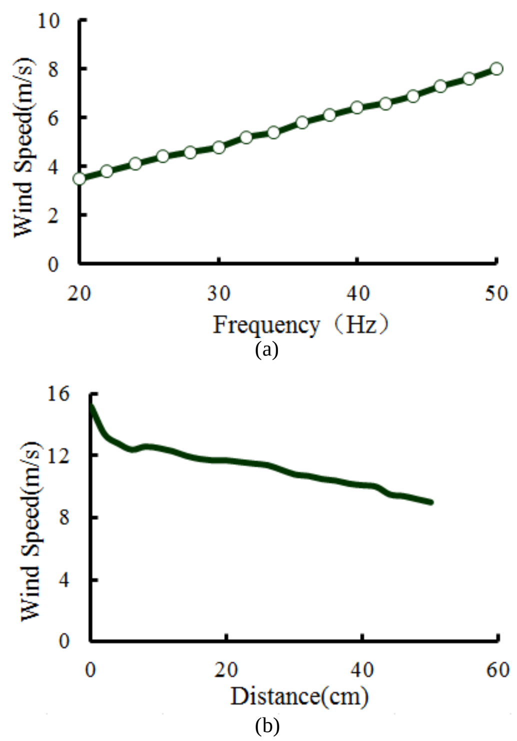

Figure 4. Wind speed vs (a) frequency and (b) distance

Figure 5 shows the relationship between the generated voltage and excited angle at the weight of proof mass is 0g. The curves in Figure 5 shows that there are several optimal excited angles for the PWEH to achieve peak voltage at speed of 6.8/10/11.8/14.9m/s. Under the excited angle is given, the peak voltages rise with the increasing of wind speed, but the peak voltages decrease with the increasing of excited angle when the wind speed is given. From the experimental data, the achieved maximum peak voltages from the PWEH at speed of 6.8/10/11.8/14.9m/s are 0.88/1.48/2.56/2.96V respectively and optimal excited angles speeds are 45/30/45/30°respectively.

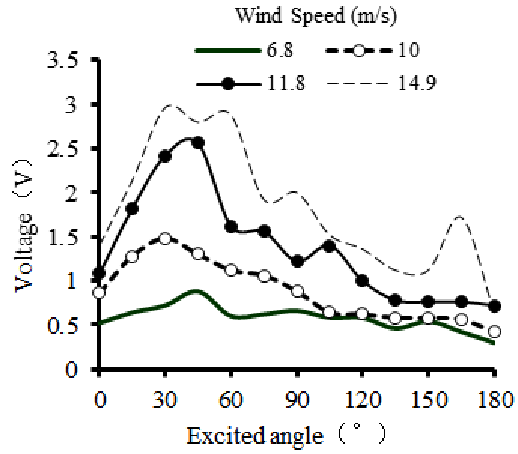

Figure 5. Generated voltage vs excited angle at the weight of proof mass is 0g

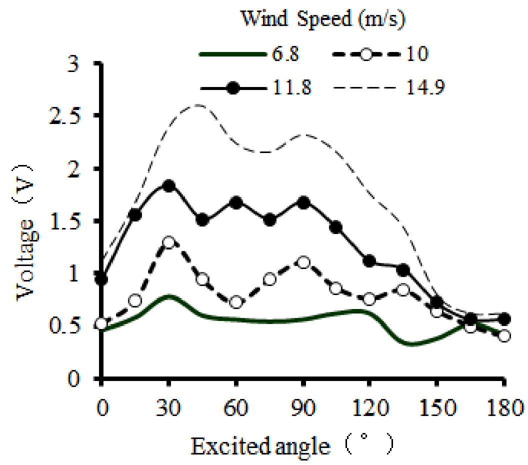

Figure 6. Generated voltage vs excited angle at the weight of proof mass is 4.37g

Figure 6 presents the relationship between the generated voltage and excited angle at the weight of proof mass is 4.37g. The curves in Figure 6 show that the achieved optimal excited angles for the PWEH at speed of 6.8/10/11.8/14.9m/s are 30/30/30/45°respectively. Besides, several peak voltages at the same speed are little difference and the overall voltages drop with excited angle increasing gently.

Figure 7 shows the relationship between the generated voltage and excited angle at the weight of proof mass is 8.74g. The curves in Figure 7 show that the achieved optimal excited angles for the PWEH at speed of 6.8/10/11.8/14.9m/s are 45/60/45/45° respectively. The maximum peak voltage mutates at the speed of 14.9m/s and the voltage value is 18.2V. The reason is that stiffness of piezoelectric vibrator lowers and deformation increases when a befitting proof mass is added. Compare Figure 5, Figure 6 and Figure 7, it is obvious that adding an applicable proof mass at the end of the piezoelectric vibrator makes voltage produced by the PWEH increase.

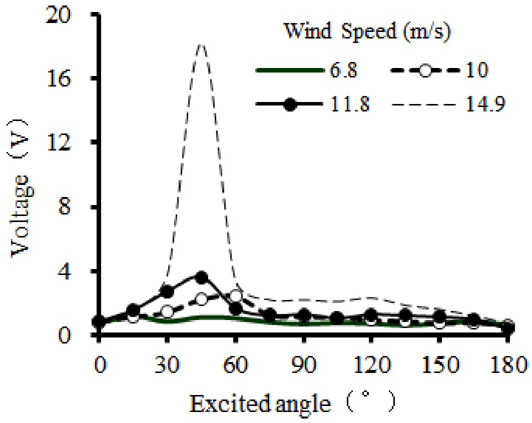

Figure 7. Generated voltage vs excited angle at the weight of proof mass is 8.74 g

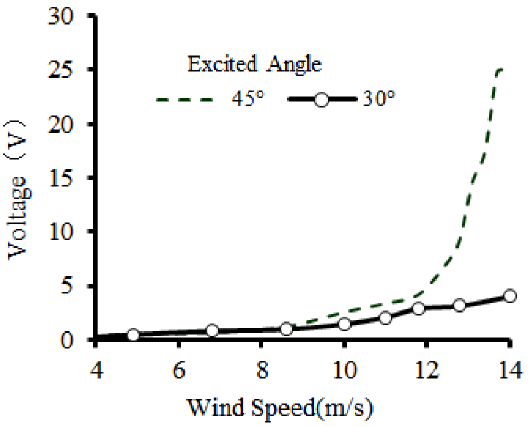

Figure 8. Generated voltage vs wind speed at the weight of proof mass is 8.74 g

Figure 8 shows the relationship between the generated voltage and wind speed at the weight of proof mass is 8.74g. In the case of constant angle, the generated voltage rises with the wind speed increases within a certain range. The generated voltage grows rapidly from 9.4 to 24.8V at the speed range of 12.8 to 14.0m/s when the excited angle is 45°. Compare curve 30° with 45° in Figure 8, the excited angle exerts great influence on the rising of voltage. Excited angle affects the windage area (the force area) of piezoelectric vibrator. Only when the weight of proof mass and the area of force area meet a correct proportion, is the excited frequency of piezoelectric vibrator and natural frequency be equal, the PWEH achieves resonance condition, and the generating performance of the PWEH is optimum.

IV. CONCLUSION

The paper presents a novel piezoelectric wind energy harvester. Making use of the force generated by the flow of wind to vibrate the piezoelectric material, the mechanical energy harvested from the vibration of the piezoelectric material is converted into electrical energy. Test results indicate that

(1) The end of piezoelectric vibrator isn't added a proof mass, the wind speed is constant, the maximum peak voltage appears between the excited angle of 30° to 45°. When the excited angle is greater than 45°, the voltage gradually decreases as the excited angle increases.

(2) In the case of constant angle, the generated voltage rises with the wind speed increased within a certain range.

(3) Adding a proof mass at the end of the piezoelectric vibrator makes voltage produced by the PWEH increase observably.

(4) When wind speeds, excited angle and the weight of proof mass meet a correct proportion, the excited frequency of piezoelectric vibrator and natural frequency is equal, the PWEH achieves resonance condition, and the generating performance of the PWEH is optimum.

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