Design and Test of a PZT Wind Generator Excited by Rotary Magnet

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KEYWORD: PZT; Wind; Energy generation; Rotating excitation

ABSTRACT: To meet the demands of rotating machine monitoring system for self-power, a novel PZT wind generator (PWG) was presented. The influence of magnetic force (number and configuration of the magnets) and wind speed on energy generation of the PWG was investigated experimentally. The research results show that there are several optimal wind speeds for the PWG to achieve peak voltages at speed range of 3 to 13m/s. The optimal wind speed value decreases, and the output voltage rising with the number of rotating magnets increasing under given number of magnets fixed on PZT. The optimal wind speed decreases and the relative voltage rises with the number of magnets fixed on PZT increasing under the given number of rotating magnets. Besides, when wind speed, number and configuration of the magnets meet an appropriate matching, the generating capacity can be improved obviously.

INTRODUCTION

Wind energy is widespread in the nature, and the wind power generation has become one major energy sources. The research that people did in the only paid attention to the large-scale wind power generation system. However, wind turbines providing sustained energy for increasingly mature wireless sensor networks which applies to environmental monitoring, large buildings and bridges monitoring, industry, military, public safety and other areas studies, received extensive attention of scholars in recent years. The chemical battery needs to be changed frequently because the energy is limited, and the life is much less than the life of wireless sensor monitoring system, which severely restricted the application of the wireless sensor network monitoring system in remote and hazardous environments(Wang et al. 2012).

With 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 PZT energy generators, such and the vibration generators (Harb 2011, Saadon and Sidek 2011) and the rotary generators (Janphuang et al. 2011, Tien and Goo 2010).

Traditional wind generator is rotated by wind, then use the electromagnetic induction generator. This wind generator can effectively use wind energy, but the processing and assembly is complex, high production costs. And its efficiency will significantly reduce when the fan size and wind speed are decreasing. The PZT material has a higher efficiency in the collection of wind energy by small size generator. Compared to conventional magnetic and electric generators, usually produce a relatively high voltage and low current that more suitable for powering on low-power electronic devices (Chen et al. 2013).

STRUCTURE AND WORK PRINCIPLE

The PWG presented (as showed in Fig.1) consists of a group of PZT, rotator, rotation axis, impeller, magnets fixed on the cantilever end, and rotating magnets bonded on the rotator. A group or multi-group of the rotating magnets is fixed on the rotator. Under the effect of fluid, the impeller drives the rotator to rotate. When the rotating magnets close to the magnets fixed on the piezo-cantilever, magnetic force between the magnets is generated for the piezo-cantilever to bend. Repulsive force is generated when the same magnetic poles close to each other, while attractive force is generated between the different magnetic poles. With the rotating magnet rotating away from the fixed magnets,

magnetic force disappears and the peizo-beam deforms reversely under its own elastic force (or continued free vibration). In this way, the mechanical energy is converted into electrical energy.

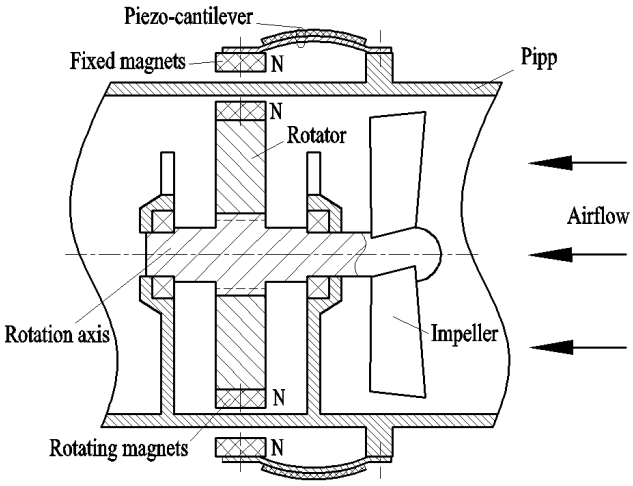

Figure 1. Schematic diagram of the PWG

Due to the non-contact magnetic force is used to excite the piezo-cantilever, the proposed rotatory PZT generator has advantages of no impacts and noises during the work process. At the same time, it is easy for the exciting force to be adjusted with changing the strength of the magnetic field or distance between the rotating magnets and nickel plate. Theoretically, the PZT generator is able to generate effective electrical energy in a variety of speeds. When the magnetic force between the rotating magnets and nickel plate are given, the open-circuit voltage and power generated by the piezo-cantilever can be given as (Kan et al. 2008, Kan et al. 2011)

$$V_g = -\frac{3a(1-a)b\, g_{31} L}{l_1 W h} F \tag{1}$$

$$U_g = \frac{1}{2} C_f V_g^2 \tag{2}$$

Where $l_1 = a^4(1-b)^2 - 2a(2a^2-3a+2)\mathrm{x}(1-b)+1$, $l_2 = l_1(1-a+ab)(1+k_{31}^2) - 3a^2\mathrm{x}(1-a)b^2k_{31}^2$, $C_f = \frac{(1-a+ab)l_1 WL}{(1-a)b_{33}^T l_2 h}$ is the free capacitance of piezo-cantilever, $L/W/h$ are the length/width/thickness of the piezo- cantilever respectively, $a = h_m / h$ is the thickness ratio, h_m is the thickness of the metal substrate, g_{31} is the piezoelectric voltage constant, $b = E_m / E_p$ is the Young's modulus ratio, E_p and E_m are the Young's modulus of piezoelectric and substrate element respectively, $k_{31}^2 = E_p g_{31}^2 / b_{33}^T$, $b_{33}^T = 1/e_{33}^T$ is the dielectric isolation rate, $e_{33}^T = 1330e_0$ is the dielectric constant of the piezoelectric ceramic in the thickness direction, F is the exciting magnetic force.
Wind energy is generally calculated by the wind speed:

$$E = \frac{1}{2} \mathrm{m} v^2 \tag{3}$$

$$m = r A v \Delta t \tag{4}$$

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 (Ji 2010).

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

C_p 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 inversely proportional to the cubic wind speed, which can be seen, wind speed is an important factor affecting the wind energy.

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 (showed in Fig.2). To verify the feasibility of the PWG presented, and obtain the effect of related factors on its power generation performance, an experimental prototype is fabricated and tested (as showed in Fig.3). The main test equipment mainly include an AC blower (maximum wind pressure is 1000Mp, air volume of 14m^3/min), a frequency converter (the range of adjustment is 0-50Hz, FM step 0.2Hz), and an oscilloscope. The measure of the PZT vibrator is 39 × 45 × 0.5mm^3, preflex radius is 106mm and the proof mass is ø12 × 4mm^3 and 4.37g.

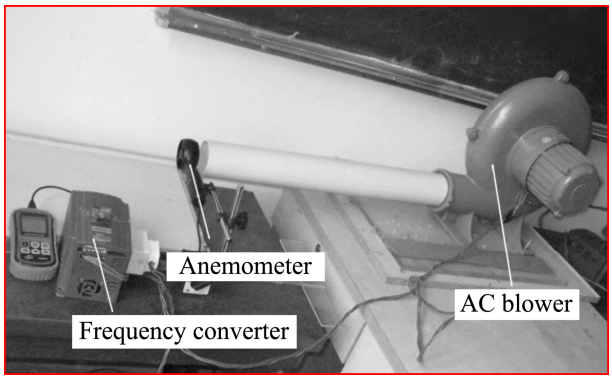

Figure 2. Photo of the wind speed test system

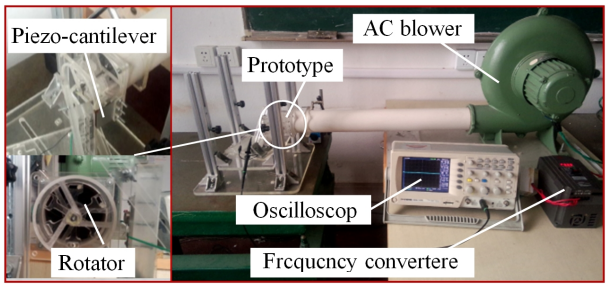

Figure 3. Photo of the PPDWG and test system

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

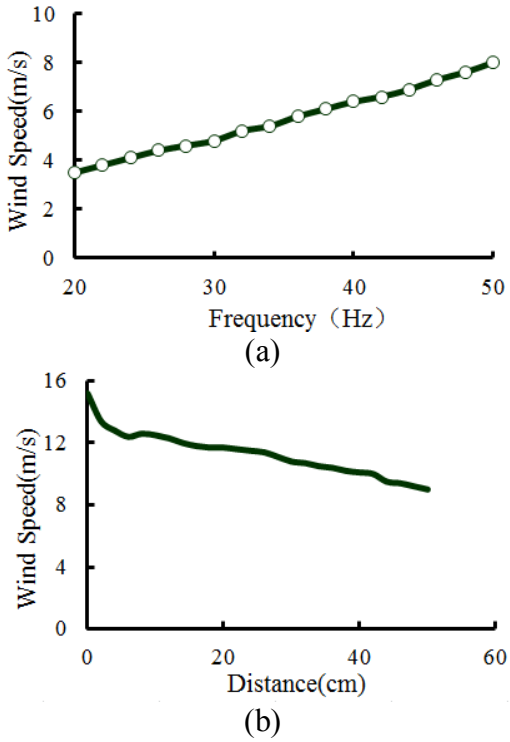

Figure 4. Wind speed vs (a) frequency and (b) distance

Figure 5 shows the relationship between the generated voltage and wind speed with one rotating magnet fixed on the free-end of piezo-cantilever and 2/3/6 rotating magnet fixed on the rotator in circumferential direction. The curves in Figure 5 show that there are several optimal wind speeds for the PWG to achieve peak voltage at speed range of 3 to 13 m/s. Under a given number of magnets fixed on the free-end of the piezo-cantilever, the peak voltages rise with the increasing of the number of rotating magnets and wind speed. At wind speed of 11.83/8.72/5.95 m/s, the achieved peek voltages from the PWG with 2/3/6 rotating magnets fixed in circumferential direction of the rotator are 27.0/34.8/37.2 V respectively.

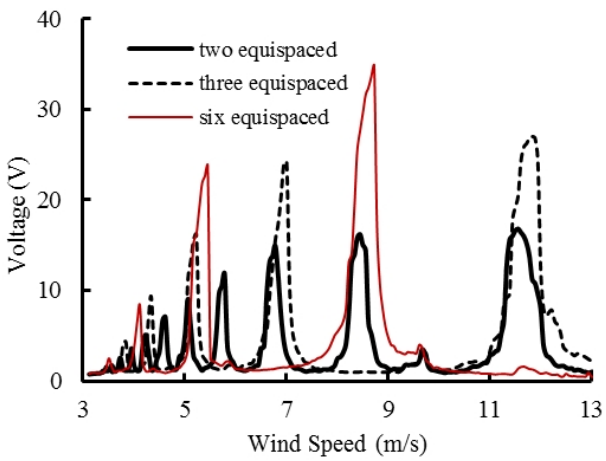

Figure 5. Generated voltage vs wind speed under the different number of rotating magnets

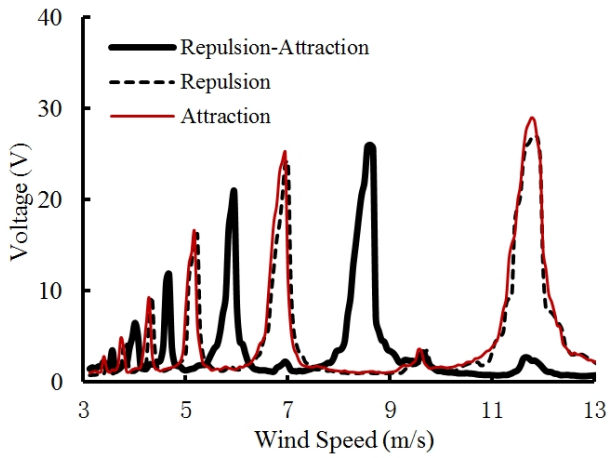

Figure 6. The influence of configuration mode of magnets on generated voltage

Figure 6 presents the relationship between the generated voltage and the configuration modes of rotating magnets under the same number of rotating magnets. The curves in Figure 6 show that the configuration modes of rotating magnets and the fixed magnets (repulsion, attraction, or repulsion-attraction) exert great influence on the peak voltage and the relatively optimal wind speeds. The relative peak voltage rises and the optimal wind speed forwards gradually, when the rotating magnet configuration mode changes from the repulsion/attraction/one repulsion and another attraction under the given numbers of the rotating magnet. In the case of two magnets rotating, the peek voltages and optimal wind speeds of the PWG with given magnets fixed on piezo-cantilever are 27.0/29.0/26.0V and 11.83/11.77/8.61m/s respectively, when the rotating magnet configuration mode changes as above.

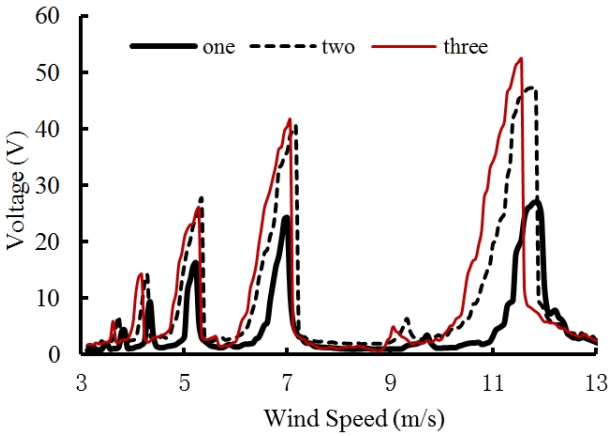

Figure 7. Generated voltage vs wind speed under the different number of fixed magnets

Figure 7 shows the relationship between the generated voltage and wind speed with two rotating magnet fixed on the rotator in circumferential direction and 1/2/3 rotating magnet fixed on the free-end of piezo-cantilever. The curves in Figure 7 show that the optimal wind speed value decreases, and the output voltage rising with the number of rotating magnets increasing under given number of magnets fixed on PZT. The achieved peek voltages of the PWG with 1/2/3 fixed magnets fixed on the free-end of piezo- cantilever are 27.0/47.3/52.4V respectively under the wind speed of 11.83/11.77/11.55 m/s.

CONCLUSIONS

The paper present a novel PZT wind generator (PWG) excited by the coupling effect between rotating magnets and those fixed on the PZT was presented. The influence of magnetic force (number and

configuration of the magnets) and wind speed on energy generation of the PWG was investigated experimentally. The research results show that there are several optimal wind speed for the PWG to achieve peak voltages at speed range of 3 to 13m/s. The optimal wind speed value decreases, and the output voltage rising with the number of rotating magnets increasing under given number of magnets fixed on PZT. The optimal wind speed decreases and the relative voltage rises with the number of magnets fixed on PZT increasing under the given number of rotating magnets. The configuration modes of rotating magnets and the fixed magnets (repulsion, attraction, or repulsion-attraction) exert great influence on the peak voltage and the relatively optimal wind speed. Besides, when wind speed, number and configuration of the magnets meet a appropriate matching, the generating capacity can be improved obviously. The test results show the feasibility of the PZT pipe wind driven generator and validity of theoretical results.

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