Flexible piezoelectric wind energy generator

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Abstract. This paper proposes the scheme of a flexible piezoelectric generator. The generator using direct piezoelectricity of PVDF, can covert wind power to charge output. It possesses such advantages as: light, small-sized and better flexibility. Using FEA method, this paper carries out modal analysis and harmonic response analysis for the generator. From the modal analysis results, we get the generator's the first for modal are 6.95 Hz, 43.51 Hz, 76.06 Hz and 122.84 Hz. From harmonic response analysis results, we get the amplitude-frequency characteristic curve of the generator's output voltage, and the results show that the generator will generate higher voltage when it vibration in second-order than first –order. In order to verify the accuracy of simulation, a series experiments are carried out. Simulation and experiment on the generator proved the reliability in the wind and shows the excellent quality of generating electric energy.

Introduction

Traditional battery is not suitable in some special applications because of its short life, large size and short storage time, which means it needs to be replaced or recharged regularly. As self-powered equipments are wildly used, the study on energy generators that can convert ambient physical energy into electric energy has attracted more and more attention. Among different kinds of energy generators, piezoelectric generator, based on piezoelectric materials, which can convert mechanical energy to electric energy, has been studied on extensively. It includes two categories [1]: vibrating piezoelectric generator and stamping type piezoelectric generator.

The most extensivly studied in other countries about stamping type piezoelectric generator is piezoelectric power generation shoes [2, 3]. The researchers put piezoelectric ceramic at the buttom of the shoes and convert the stamping energy when walking into electic enerage. In 2010, D.St.Clair et al. [4] placed a piezoelectric patch on a cantilever, and acquired 0.8mW output power when wind speed was 12.5m/s. But the size of it is big. X. He Xuefeng et al. [5] studied a stamping type piezoelectric generator in 2013. When the splitter plate stamping the cantilever, the piezoelectric layer will be changed by the force and generate electric power. This generator can acquire 64μW output power when the wind speed is 15m/s and the ideal load is 200Ω.

When piezoelectric generator is designed for a certain use, it must work reliable in special environment. The ambient energy is wind and the speed is 50m/s. And in15s, the generator have to charge capacitor to 5V.

Flexible piezoelectric generator

The piezoelectric material used in this paper is PVDF (Polyvinylidene Fluoride). Basic theory is positive piezoelectric effect. The power generator mode of the flexible piezoelectric generator (hereinafter referred to as generator) in this paper is d31,which means the electric field direction perpendicular to the stress direction in the material as shown in Fig.1

Flexible generator is based on the wind-induced vibration theory. Just like a flag, one end of the generator is fixed, and the other one is free. Fig.2 shows when wind comes from the fixed end, the generator vibrates and causes stress inside, and therefore it will generate electric charge.

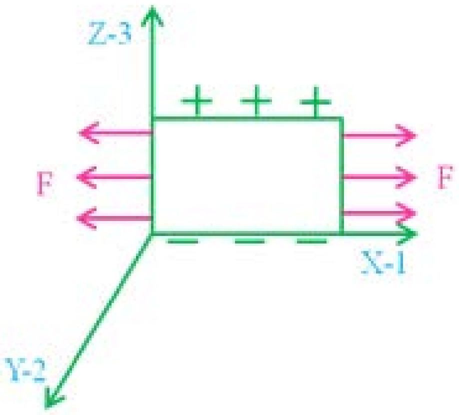


Fig.1 Piezoelectric material’s d31 mode

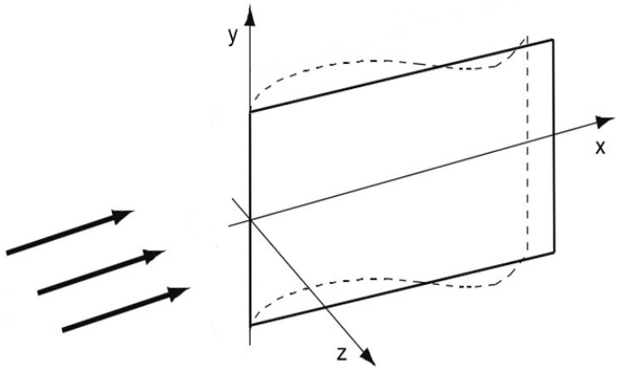


Fig.2 simplified model of the generator

The simulation of flexible piezoelectric generator

The vibration of the generator is complex, modal and harmonic analysis are used in ANSYS to get a general understanding of the generator.

Simplified structure of the generator is shown in Fig.3, and the dimension is 50mm×10mm×0.04mm (L×W×H). The thickness of PVDF is 0.03mm and the 304 stainless steel base is 0.01mm. Because the stiffness of insulation is so low that is can hardly affect the vibration characteristic of the generator, hence it can be ignored when modeling. Material parameters of PVDF and 304 stainless steel base are listed in Table 1.

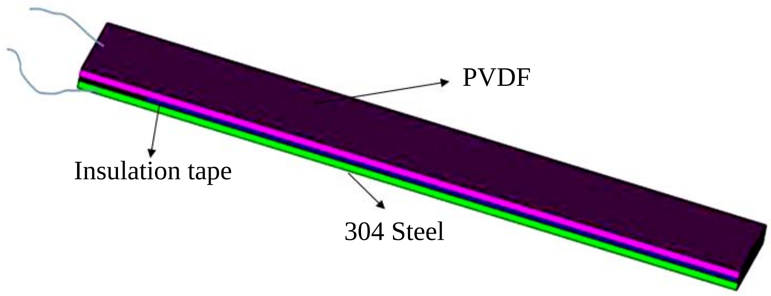


Fig. 3 Simplified structure of the piezoelectric generator

Table 1 Material parameters of PVDF and 304 stainless steel base

	Density [kg/m^3]	elasticity modulus [N/m^2]	Poisson's ratio
PVDF	1780	3.0×10^{9}	0.3
304 steel base	7930	2.0×10^{11}	0.29

Y.Watanabe et al. [6] studied the vibration characteristics of flexible paper and found that with the speed of wind increasing, the vibration order of vibrator changes and the first four orders are most important. As the characteristics of the generator are similar to the paper, modal analysis just covers the first four orders.

Fig.4 shows the vibration mode of the four orders, and then natural frequencies are 6.95 Hz, 43.51 Hz, 76.06 Hz and 122.84 Hz.

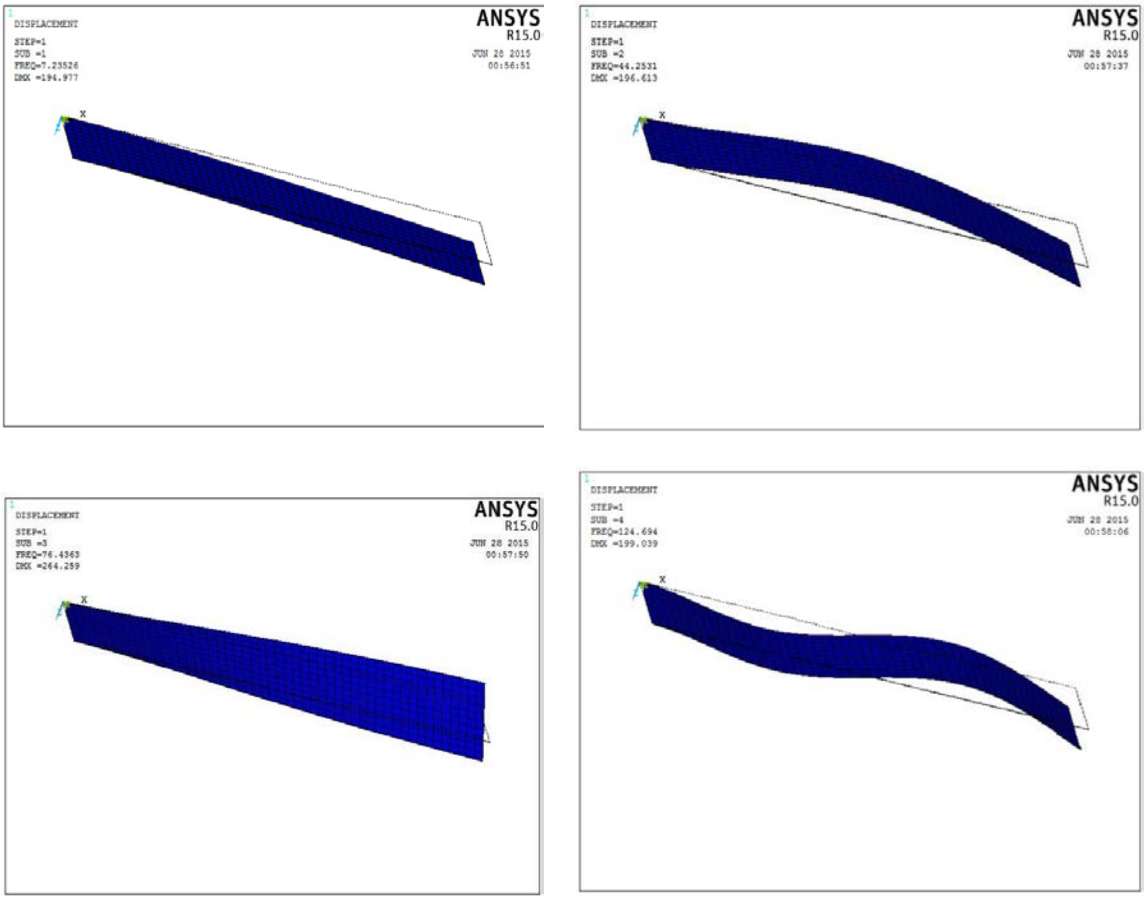


Fig. 4 The configuration of first four vibration orders

Harmonic analysis can tell which frequencies can generate higher voltage. In Fig.5, the third order vibration is torsion which can reduce the life of the generator. And the wind speed to generate the fourth order is relatively high that cannot achieve in laboratory. So the frequency when doing harmonic analysis can just covers the first two orders. The result shows in Fig.5. There are two peaks at the first order natural frequency separately, and the latter one has higher voltage than the former. It can be concluded that the output voltage reach the peak when the external excitation frequency is close to the natural frequency.

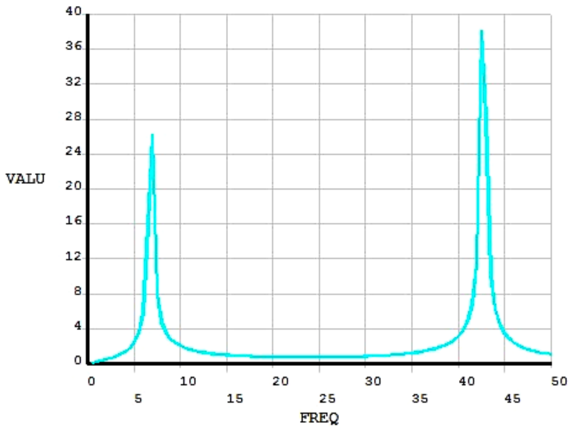


Fig. 5 The harmonic analysis of the generator

Experiment setup

Fig.4 shows the generator has four parts: PVDF, insulation, 304 steel and electrode. The test system include: air blower, test fixture, oscilloscope, anemometer and voltage source. The air blower's rated voltage is 220V and can provide wind speed ranges from 0-50m/s. Picture of the test system is shown in Fig.6.

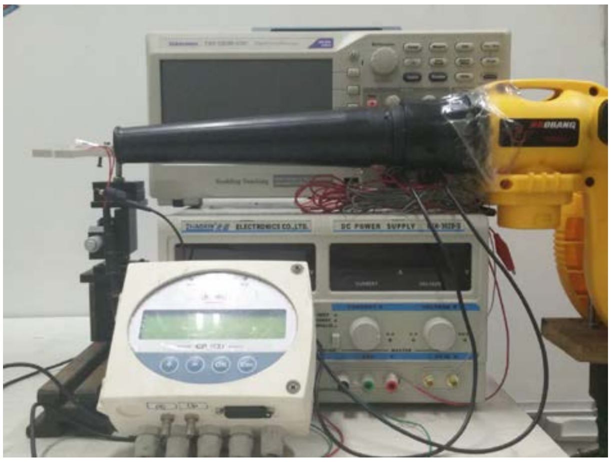
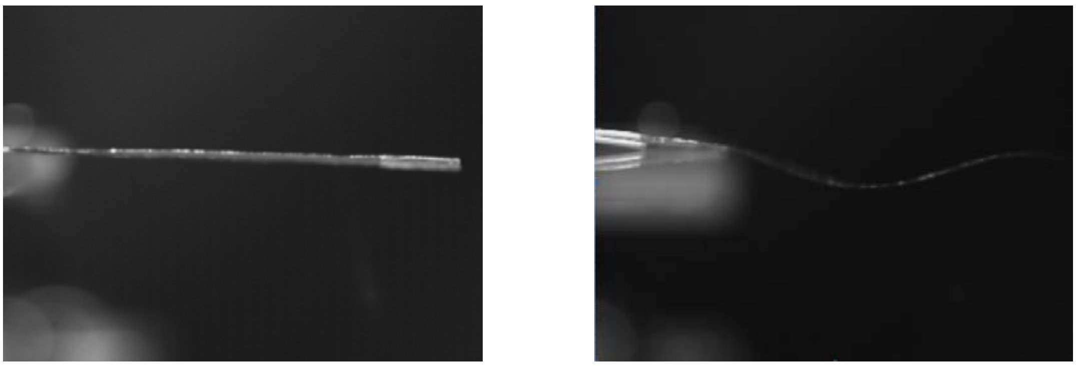


Fig.6 Picture of the test system

Experiment results and discussion



(a) Vibration under low wind speed (b) Vibration under high wind speed

Fig.7 Vibration mode of the generator under different wind speed

Use high-speed camera to take photos of the generator in low and high wind speed and the vibration mode can be seen in Fig.7. The left one shows the first order vibration mode, while the other one shows the second order.

Connect the two electrodes to oscilloscope and change the wind speed from 5m/s to 50m/s, with the increment of 5m/s at each time. Fig. 8 shows the waveform of the output voltage when the generator is in resonance. The wind speed is 30m/s and the output voltage is 45.2V at a frequency of 62.5Hz.

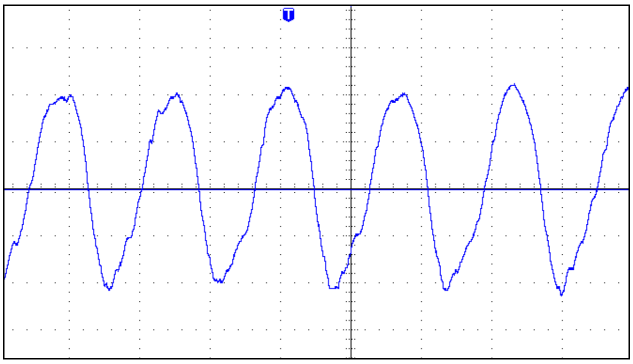


Fig.8 Waveform of the output voltage

Record the corresponding output voltage under the different wind speed, and then use the wind speed as X axis and voltage as Y axis to plot. As shown in Fig.9 when the wind speed is low, the output voltage is almost zero. When wind speed reaches a certain value, the voltage increases suddenly. The reason is that the ability to generate electric power is stronger in the second vibration mode than that in the first mode. The frequency under the certain wind speed approximate the second order vibration frequency.

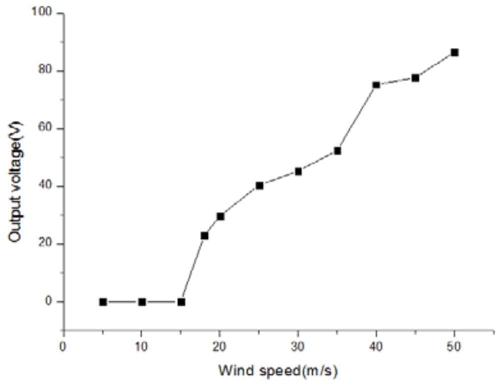


Fig.9 Output voltage in different wind speed

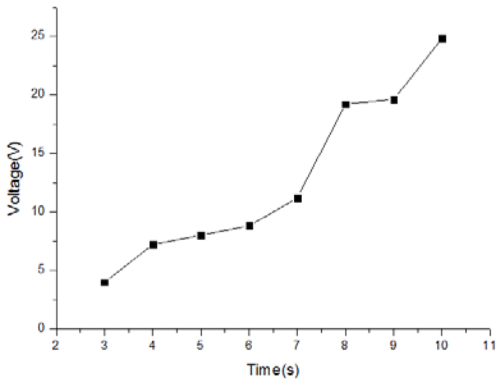


Fig.10 Charge voltage of capacitance

Before the electric energy is stored in a capacitor, the AC output voltage is changed into DC voltage by using an AC/DC conversion chip. Parameters of the capacitor are 25V, 10μF. In order to improve reliability, the charge test is limited in 10s rather than 15s. Record the voltage of the capacitor every second and plot Fig. 10. The wind speed cannot stay stable at 50m/s, so we choose 45m/s instead. When charged for 10s, the voltage can reach 24.8V, which is much more than required.

Conclusion

The paper studied a flexible piezoelectric generator for a special use. The simulation and experiment result show that the generator can perfectly meet the need. In addition, the generator possesses several advantages such as light, small-sized, better flexible and so on. Subsequent research work of generator will focuses on the influence of different structures.

References

[1] Nathan S.Shenck, Joseph A.Paradiso. Energy Scavenging with Shoe-Mounted Piezoelectrics[J]. IEEE Micro, 2001, 21(3), 30-42.

[2] Nathan S.Shenck, Joseph A.Paradiso. Energy Scavenging with Shoe-Mounted Piezoelectrics[J]. IEEE Micro, 2001, 21(3), 30-42.

[3] Stacy J.Morris, Joseph A.Paradis. Shoe-Integrated Sensor System for Wireless Gait Analysis and Real-Time Feedback. Proceedings of the Second Joint EMBS/BMES Conference Houston[C]. USA, 2002: 23-26.

[4] Clair D S, Bibo A, Sennakesavababu V R, etal. A Scalable Concept for Micropower Generation using Flow-induced Self-excited Oscillations[J]. Applied Physics Letters, 2010, 96(14): 144103.

[5] He Xuefeng, Gao Jun, Xia Huilu. Experiment Studies on Impact-Based Piezoelectric Wind Energy Harvester[J]. Nanotechnology and Precision Engineering, 2013, 11(3): 191-195.

[6] Watanabe Y, Suzuki S, Sugihara M, et al. A theoretical study of paper flutter[J]. Journal of Fluids and Structures, 2002, 16(4): 543-560.