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Cut-corner prism piezoelectric energy harvester based on galloping enhancement mechanism

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SUMMARY:
To improve the efficiency of harvesting energy, a cut-corner prism piezoelectric energy harvester based on galloping enhancement is designed in this study. Galloping is caused by the pressure difference between the upper and lower surfaces of the prism. Numerical simulations indicate that the cut-corner can reduce the occurrence of the shear layer reattachment phenomenon and also increase the strength of the secondary backflow between the shear layer and the lateral side of the prism, thereby raising the pressure difference between the upper and lower surfaces of the prism. The effect of cut-corner size on the performance is investigated experimentally. The results show that the optimal range for the prism is when the lengths of the cut-corner windward side and parallel side are 0.2B–0.4B (B is the length of the prism side) and 0.5B–0.6B, respectively. At a wind speed of 6.24 m/s and a resistance of 1×10^5 Ω, the maximum output power of the cut-corner prism energy harvester with a windward side length of 0.4B and a parallel side length of 0.6B can reach 47.5 mW, which is 261% higher than that of the reference square prism, effectively raising the performance of the piezoelectric energy harvester.

Keywords: Galloping enhancement, Piezoelectric energy harvester, Secondary flow

1. MOTIVATIONS

Airflow plays a major part in industrial production as it possesses a huge amount of kinetic energy, with examples including the exhaust port of pneumatic components and gas piping. Currently, the conversion of kinetic energy in fluid into electrical energy has been a long-standing challenge. Compared with electrostatic and electromagnetic methods, piezoelectric energy harvesters have the advantages of high energy density, high reliability, and miniaturization of size(Asghari and Dardel, 2020). Meanwhile, compare several different types of vibration ways, galloping is a dispersive cross-flow self-excited vibration which is very beneficial for energy harvesting.

Many studies have analysed galloping based on the quasi-steady theory proposed by (Parkinson and Engineering, 1964) and (Parkinson and Brooks, 1961). However, the coefficient of the galloping force does not directly reveal the interaction between the fluid and the prism. Therefore, this study aims to investigate the physical mechanism of galloping enhancement from the separation and reattachment of shear layer with different prism shapes and use the findings to design a highly efficient energy harvester.

2. METHODS AND RESULTS

(Parkinson, 1971) demonstrated that for a square prism, when the angle of attack was about 13°, the shear layer that had separated from the leading-edge corners of the prism reattached to the vicinity of the trailing-edge corners. As a result, this reattachment phenomenon substantially reduced the amplitude of galloping.

Moreover, (Parkinson, 1989) explained that galloping is excited by an unbalanced pressure distribution acting on the lateral side of the afterbody, which requires a secondary flow of sufficient strength between the lateral side of the square prism and the shear layer, and a sufficient region of interaction to produce an ample pressure difference to overcome the external damping and caused vibration. This also indicates that higher amplitude vibration can be achieved only when d/h is large enough (d and h is width and length, respectively). Based on the above analysis of the galloping mechanism, a cut-corner prism is designed as shown in Fig.1 in this study to avoid the occurrence of reattachment of the shear layer on the side of the prism as much as possible and increase the strength of the secondary backflow.

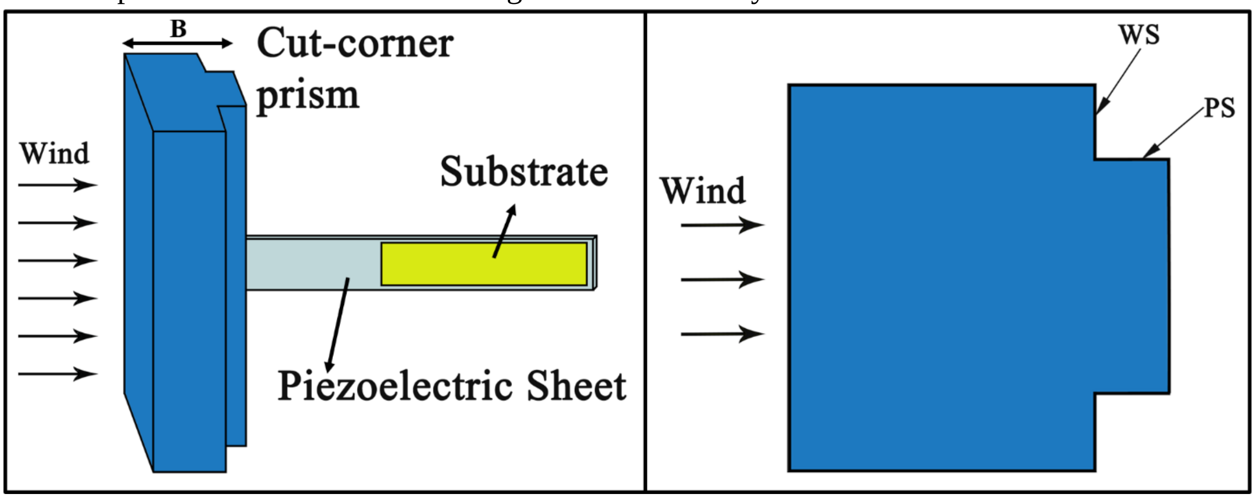

Figure 1. Schematic diagram of the cut-corner prism energy harvester.

Fig .2 shows the maximum output power for different windward and parallel sides of the cut-corner prism piezoelectric energy harvesters. And WS = 0.2B–0.4B and PS = 0.5B–0.6B are the optimal ranges for the designed prisms. (WS = Windward Side, PS = Parallel Side).

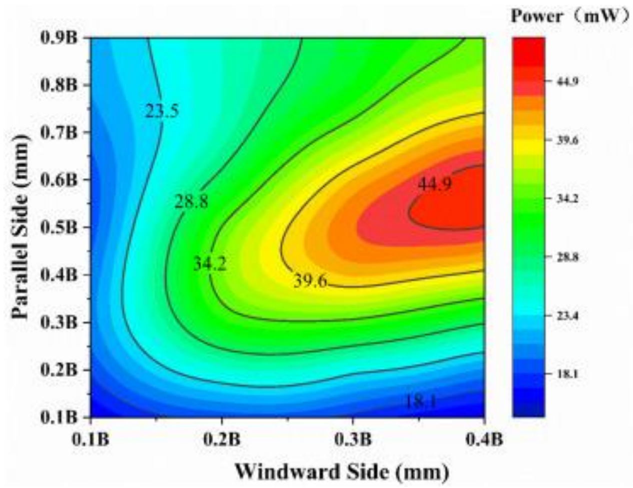

Figure 2. Maximum output power for different windward and parallel sides of the cut-corner prism piezoelectric energy harvesters.

Meanwhile, a summary has been presented in Table 1 to shown the advantage of the cut-corner prism.

Table 1. Summary of the current research on the prism shape of energy harvester

Shape	Maximum Output	Investigator
Cylinder	3.36μW	(Hu et al., 2018)
Square	8.4mW	(Yang et al., 2013)
Rectangular	5.8mW	(Yang et al., 2013)
D-shape	1.14mW	(Sirohi and Mahadic, 2012)
Trapezoidal	5.4μW	(Zhang et al., 2020)
Reverse trapezoidal	17.65μW	(Zhang et al., 2020)
Square with V-shaped groove	1.25mW	(Zhao et al., 2019)
Bulb-shaped	6.27μW	(Sun et al., 2019)
Funnel-shaped	4.3mW	(Zhao et al., 2020)
Rods attached on the circular cylinder	71.4μW	(Hu et al., 2018)
Cut-corner	47.54mW	Present

3. CONCLUSIONS

This study, based on a galloping enhancement mechanism, investigates the performance of a cut-corner prism piezoelectric energy harvester with the cut-corner located on the leeward side. The existence of the cut-corner region eliminates the reattachment of the shear layer. It greatly increases the strength of the secondary backflow between the shear layer and the lateral side. Furthermore, the high-intensity secondary backflow between the shear layer and the lateral side of the cut-corner prism plays a dominant role in improving the energy harvesting efficiency. Subsequently, the influence of the side length on the output power is studied by varying the length of the windward side WS and the parallel side PS of the cut-corner region. From the experimental results, both WS and PS show very important effects. WS = 0.2B–0.4B and PS = 0.5B–0.6B are the optimal ranges for the designed prisms. Among them, the output power is the highest in the case of WS = 0.4B, PS = 0.6B. The maximum output power is 47.54 mW at a wind speed of 6.24 m/s, which is 261% higher than that of the energy harvester with a square prism.

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