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AIRFLOW ENERGY HARVESTING - A DYNAMIC REGULATING MECHANISM FOR INCREASED AIRFLOW SPEED RANGE IN MICRO PIEZOELECTRIC TURBINES

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INTRODUCTION

- **Piezoelectric air turbines**: increasingly popular in flow energy harvesting due to simplicity in structure and high output voltage.
- **Cut-in (start-up) speed**: main hindrance to harness **low-speed** airflow energy.
- **Solution:** Weakening magnetic coupling before start-up to reduce cut-in speed.
- **Requirement**: The coupling should be enhanced after start-up to maintain the output power.

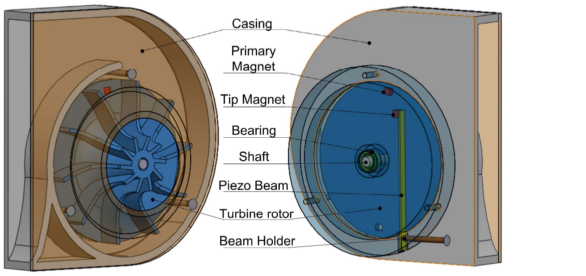

FIGURE 1 General configuration of piezoelectric wind turbines [1].

- **Turbine's transduction**: magnetic "plucking" of piezoelectric beam by passing rotor.

PIEZOELECTRIC TURBINE WITH SELF-REGULATION

- Passive regulating mechanism - designed to adjust the magnetic coupling with regard to airflow speed.
- Realization - **centrifugal governor system** consisting of a micro-spring, a rotating magnet and two guiding rails.

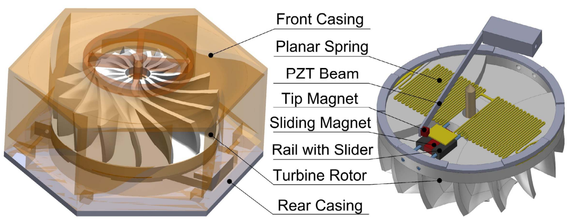

FIGURE 2 Design of the micro piezoelectric turbine, showing the implementation of the self-regulating mechanism.

- Magnetic coupling should be weak before start-up and intensified when the device is in operation.
- Spring constant should be properly designed, enabling the system to have a low cut-in speed and high output power after start-up.

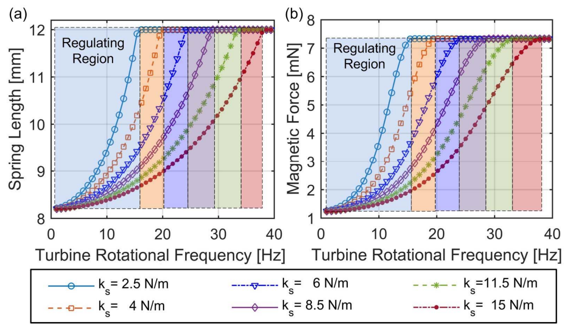

FIGURE 3 Simulated self-regulating behaviour with different spring constants. (a) Spring length versus turbine rotational frequency and (b) peak magnetic force in the y direction versus rotational frequency [2].

MICRO-PLANAR SPRING

- Different shapes and parameters were investigated for the spring design.
- U-shape spring has the lowest spring constant.

TABLE 1 Simulated spring constant with different shapes and equivalent dimensions.

Shape	Spring constant (N/mm)
Square shape	0.590
V-shape	0.580
Sine shape	0.583
U-shape	**0.311**

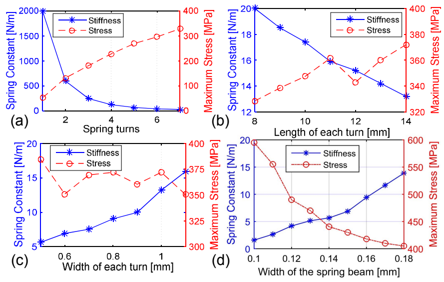

FIGURE 4 Simulated spring constant and maximum stress of the U-shape spring versus different design parameters. (a) Spring turns, (b) length of each turn, (c) width of each turn and (d) width of each spring beam. Spring constant is more sensitive to the variation of spring turns and beam width.

- The FEM simulation provides the feasible shapes and structural parameters for a ultra-low-stiffness spring (Spring constant: 1.58 N/m).

FABRICATION AND TESTS

- Titanium foil: 200 μm thickness
- Laser machining
- Elastic limit: 910 MPa
- Spring constant: 0.78 N/m
  (Fabrication & test inaccuracy)

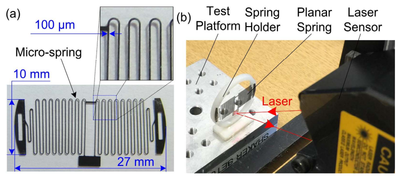

FIGURE 5 Micro-spring and experimental set-up.

- Equivalent experiment set-up
- DC motor as turbine rotor
- Accurate control of the gaps of magnets in 3 dimensions

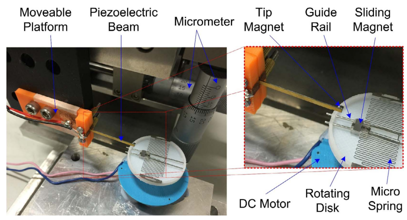

FIGURE 6 Equivalent set-up to examine the self-regulating mechanism.

RESULTS AND DISCUSSION

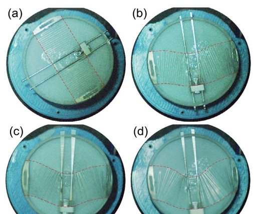

FIGURE 7 Distortion for different frequencies. (a) Static, (b) 11.1 Hz, (c) 14.2 Hz and (d) 17.9 Hz.

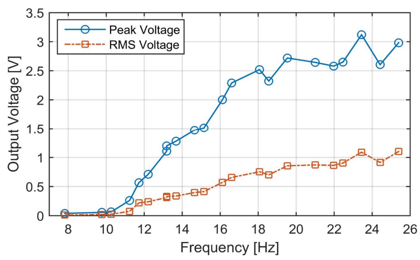

FIGURE 8 Peak and RMS voltage of the beam versus rotational frequency of the rotating disk. The regulation happens from 10 Hz to 18 Hz.

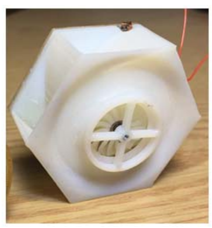

FIGURE 9 Prototype of the piezo turbine with self-regulation. Overall dimension: Φ37 mm × 18 mm.

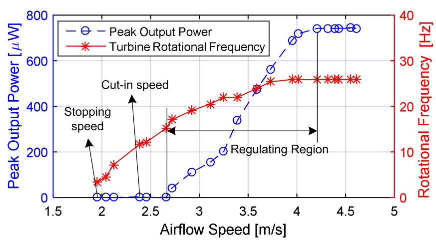

FIGURE 10 Peak output power and rotational frequency of the turbine against airflow speed with a 100 kΩ load.

CONCLUSIONS

- A piezoelectric wind turbine with self-regulation was developed.
- A micro-planar spring was designed and fabricated with ultra-low spring constant.
- A prototype of the turbine was fabricated and tested in a wind tunnel.
- The cut-in airflow speed is 2.34 m/s, showing a 30% improvement against a non-regulated harvester.

REFERENCES

1. H. Fu and E. M. Yeatman, Journal of Physics: Conf. Ser., vol. 660, 012058, 2015.
2. H. Fu and E. M. Yeatman, Applied Physics Letters, vol. 107, p. 243905, 2015.