A circular-cylinder piezoelectric energy harvester based on flow-induced flexural vibration mode and its nonlinear characteristics near resonance

***J.M. Xie[1], †Y.T. Hu[1]**

[1]Department of Mechanics, Huazhong University of Science and Technology, Wuhan, China.

*Presenting author: jemmy_1989@126.com
†Corresponding author: hudeng@263.net

Abstract

In order to operate wireless electronic devices at locations that are not conveniently accessible for wiring or battery replacement, energy harvest techniques have been developed to convert harvested environmental mechanical energy to electrical energy, which can be used for convenient device operation or battery charging. Due to the strong electromechanical coupling effect, piezoelectric materials are employed for this purpose. Recently, piezoelectric energy harvesters that are composed of flexible piezoelectric films or strips are adopted for converting mechanical energy from ambient fluids induced vibrations into electric energy[Carroll (2002); Akaydin et al. (2010); Allen and Smits (2001); Peng and Zhu (2009); Zhu and Peng (2009)]. To extract energy as much as possible, the harvesters are usually designed as resonant devices operating near resonance. We study a new piezoelectric structure for energy harvesting from flow-induced vibration. It consists of a properly poled and electroded flexible piezoelectric ceramic cylinder (Fig. 1) in a perpendicular flow. The transverse force from the flow [Fung (1969)] drives the cylinder into flexural vibrations with an electrical output. An analytical solution is obtained from which the output power and efficiency of the harvester versus outer electrodes angle are calculated and examined. For a cylinder of 40 cm in length and 1 cm in diameter in flowing air with a speed of 5 m/s, the output power is of the order of 10^{-3} watt (Fig. 2). It becomes significantly higher if the flow speed is increased. The nonlinear behaviors of this energy harvester near resonance are analyzed subsequently. The geometrically-nonlinear effect of the cylinder is studied with considering the in-plane extension incidental to the large deflection. The boundary electric charges generated from two deformation modes, flexure and in-plane extension, were distinguished with each other because the charge corresponding to the latter mode produces no contribution to the output current. Numerical results on output powers show that there are multivaluedness and jump behaviors (Fig. 6). Based on both the linear and nonlinear results, how to design the energy harvester to get the maximum output power is discussed.

Keywords: piezoelectric, energy harvesting, flow-induced vibration, nonlinear behavior

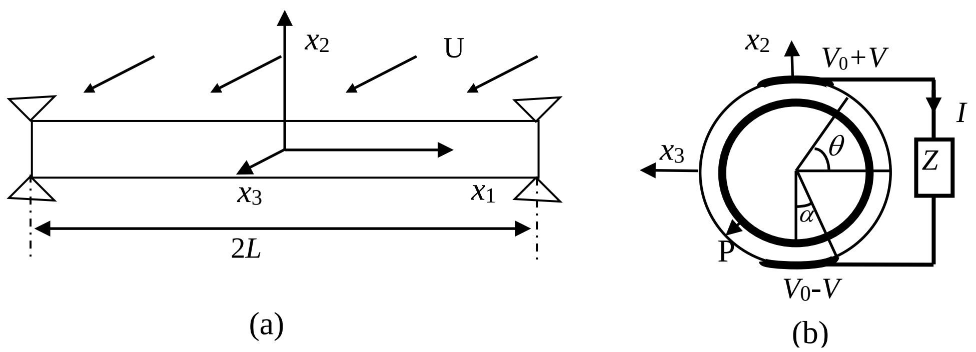

Figure 1. Side section (a) and cross section (b) of a long and thin ceramic tube in a flow as an energy harvester

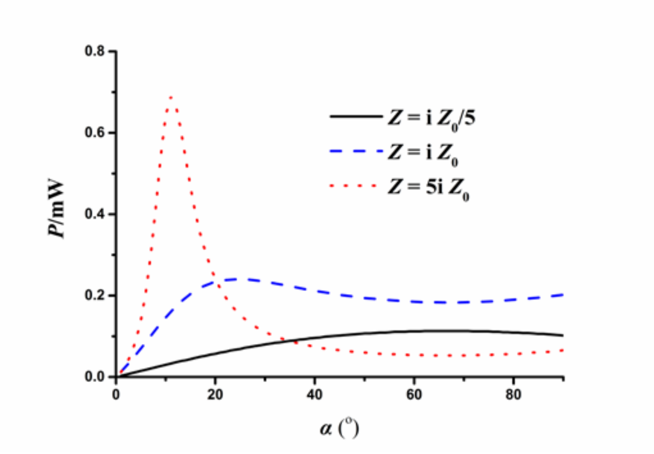

Figure 2. Output power versus outer electrodes angle for different load impedances.

The angle is varied from 0° ~ 90°. While varying the angle, we fixed the frequency at ω=630 rad/s. Both the peak value and the location of the peak depend on the load impedance.

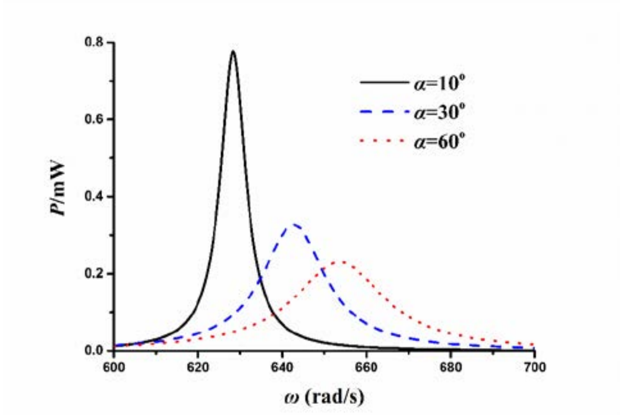

Figure 3. Output power versus driving frequency for different outer electrodes angles.

The frequency is only varied slightly around the lowest resonance of the beam. While varying the driving frequency, we fixed the load impedance at $Z=5iZ_0$. We find that the resonant frequency of the system increase but the output power decrease with the enlargement of the electrode angle.

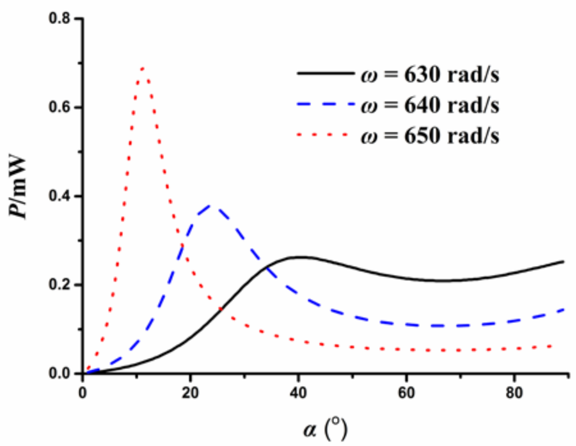

Figure 4. Output power versus outer electrodes angle for different driving frequencies.

The output power increases rapidly for small angles, reaches a maximum, and then decreases for large angles. Figure 2 3 and 4 indicate that there is an optimal value for the deriving frequency ω and the load impedance Z and the electrode angle α. At this optimal point, we can get the maximum output power.

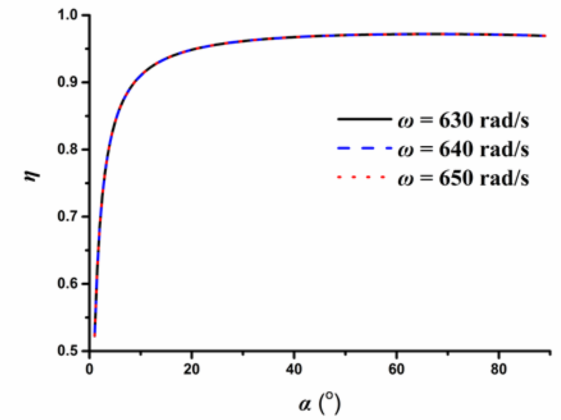

Figure 5. Efficiency versus outer electrodes angle for different driving frequencies.

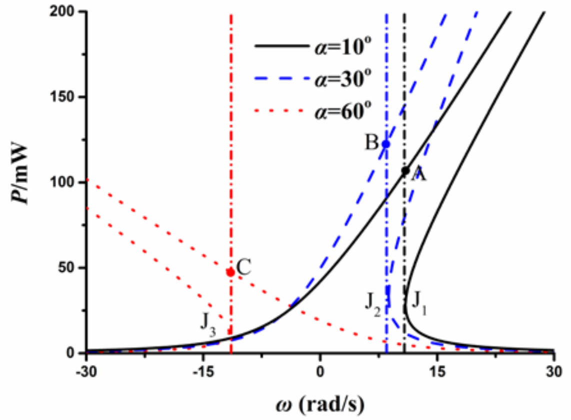

Figure 6. Output power versus driving frequency for different electrode angles near resonance

The electrode angle has influences on the magnitude of the output power and on the location of the jump phenomenon. We can find that the location of jump moves left and the output power is multivalued with jump primarily at the right of resonance (J_1A and J_2B), then change to the left of resonance (J_3C) with the increase in the electrode angle. In the meanwhile, the graph of P-$\Delta\omega$ becomes vertical first and then back to horizontal. Thus, we should design the energy harvester according to the electrode angle to avoid the multivaluedness and jump and adjacent to the resonance, otherwise, output power of the energy harvester will be either very low or unstable.

References

Carroll, C. B. (2002) Energy Harvesting Eel, United States Patent, Patent No.US-6424079-B1.

Akaydin, H. D., Elvin, N., and Andreopoulos, Y. (2010) Energy harvesting from highly unsteady fluid flows using piezoelectric materials, *Journal of Intelligent Material Systems and Structures* **21**, 1263–1278.

Allen, J. J. and Smits, A. J. (2001) Energy harvesting eel, *Journal of Fluids and Structures* **15**, 629–640.

Zhu, Q. and Peng, Z. (2009) Mode coupling and flow energy harvesting by a flapping foil, *Physics of Fluids* **21**:033601.

Peng, Z. and Zhu, Q. (2009) Energy harvesting through flow- induced oscillations of a foil, *Physics of Fluids* **21**: 123602.

Fung, Y. C. (1969) Some aeroelastic problems in civil and mechanical engineering, in: *An Introduction to the Theory of Aeroelasticity*. Ch. 2, Dover Publications, Inc., New York, USA.