Effect of Various arrangements of piezoelectric beam on Energy Harvesting of Vortex Induced Vibration of Circular Cylinder

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ABSTRACT

In this study, in order to harvest energy from vortex-induced vibration of fluid flow, piezoelectric beams mounted behind a circular cylinder are considered and effect of various arrangements of the beams are studied. To reach this goal, a three-way coupling model in the turbulent, unsteady and viscous flow regime is numerically investigated. The simulations are investigated for different values of electrical resistance and its effect on vibration amplitude, frequency ratio, voltage and power output are compared. It has been shown that the maximum oscillation amplitude and frequency ratio is occurred by a resistance value of 1000 Ω and its value decreases with the increase of resistance. Furthermore, by growing of the load resistance, the generated voltage goes up significantly and the maximum voltage is obtained in the load resistance as 100 MΩ, Contrastingly, maximum power is obtained at low values of the load resistance. Finally, it is found that in the parallel arrangement of beams, due to less damping ratio due to stronger interaction between beams and shear layers, larger vibration amplitude and much more electrical output occurs.

KEYWORDS

Vortex Induced Vibration, Energy Harvesting, Vortex Shedding, Piezoelectric, Three-way coupling.

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1. Introduction

In recent years, harvesting energy from vortex-induced vibrations (VIV) has received significant attention from researchers. Derakhshandeh [1] employed a two-way coupled model to simulate a piezoelectric cantilever beam behind a circular cylinder in a laminar flow regime. In this study, the location of the beam within the wake of the cylinder has changed. The results revealed that the lateral gap distance has a more significant impact on the dynamic response of the plate compared to the longitudinal gap distance. Wang et al. [2] also employed the finite element method to investigate the influence of gap distance and flexural stiffness on vortex shedding and the VIV response of a flexible plate behind a circular cylinder in a laminar flow regime. Jebelli et al. [3] numerically investigated the influence of simultaneous vibration of a circular cylinder and two parallel downstream flat plates. The study examined the effects of horizontal and vertical gaps between the parallel plates on vortex structure and system response. In another study, the effect of different arrangements of dual piezoelectric beams, in the absence of an upstream bluff body, has been investigated by Mazharmanesh et al. [4] Their research findings indicate that the maximum power coefficient (CP) is obtained in the tandem arrangement.

In this paper, triple piezoelectric beam configurations downstream of a circular cylinder in fluid flow is simulated, resulting in a broader lock-in regime and increased vibration amplitude of the beams, consequently leading to higher electrical output. The simulations are conducted in turbulent flow conditions at Reynolds number 14800. Additionally, a three-way coupled model is utilized, where an electromechanical model for a cantilevered piezoelectric energy harvester, based on the energy method and Euler-Bernoulli beam theory coupled with the governing equations of fluid flow (Navier-Stokes equations), is considered. Finally, three arrangements of installing piezoelectric beams, including arrangements of individual piezoelectric beam and triple piezoelectric beams with parallel and triangular configurations in the wake of the circular cylinder are numerically studied. The frequency of vortex shedding in each arrangement and the effects of electrical resistance on the amplitude of oscillations, frequency ratio, power, and generated voltage are investigated, and the configuration yielding the highest electrical output is identified.

2. Electromechanical Model for a Piezoelectric Beam

The electromechanical coupling equations and the interactions between the flow, structure and circuit are carried out by a user-defined-function (UDF) and added to the fluid flow equations. The solution of these equations for a piezoelectric cantilever energy harvester is expressed as follows:

$$\eta_r(t) = \frac{1}{\omega_{rd}} \int_{\tau=0}^{t} \left[f(t) - \chi_r \nu(\tau) \right] e^{-\zeta_r \omega_r (t-\tau)} \sin\left(\omega_{rd}(t-\tau)\right) d\tau, \qquad \chi_r = \vartheta \frac{d\phi_r(x)}{dx} \, |x = L \tag{1}$$

$$\nu(t) = e^{-t/\tau_c} \left(\int e^{t/\tau_c} \sum_{r=1}^{\infty} \varphi_r \frac{d\eta_r(t)}{dt} dt + c \right) \tag{2}$$

3. Case study

In the present study, three installation arrangement models for an inverted flag piezoelectric energy harvester are considered.

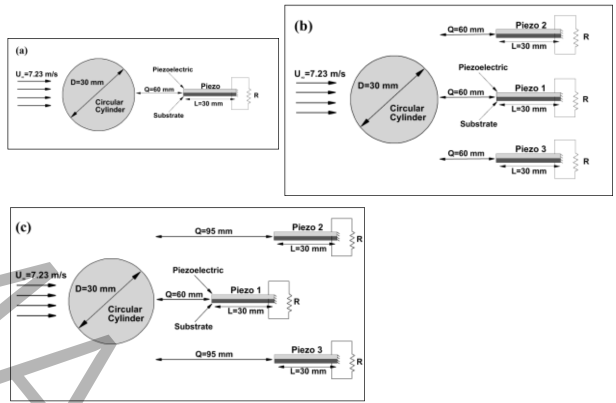

Figure 1. Schematic model of the circular cylinder and energy harvester: a) arrangement of single beam, b) parallel arrangement of three beams, c) triangular arrangement of three beams

4. Results and Discussion

In arrangements of single beam and three parallel beams, variations in the root mean square values of voltage and power with different electrical resistance values are illustrated in Figures 2 and 3, respectively. In Figure 2(a), it can be observed that with an increase in electrical resistance, the generated voltage significantly increases, reaching its maximum at 100 MΩ. Conversely, Figure 2(b) demonstrates that maximum power is achieved at low electrical resistance values due to slight fluctuations in voltage, which were previously observed within the lower range. Figures 3(a) and (b) also predict a similar behavioral pattern for the parallel arrangement of three beams as observed in Figure 2, indicating significantly higher output voltage and power in the three-beam parallel arrangement due to larger deflections.

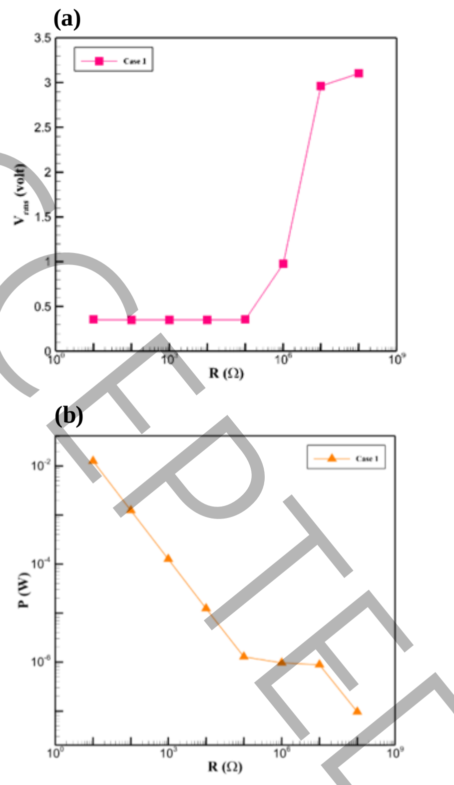

Figure 2. Variations of the, (a) voltage, (b) power output with electrical resistance in arrangement of single beam

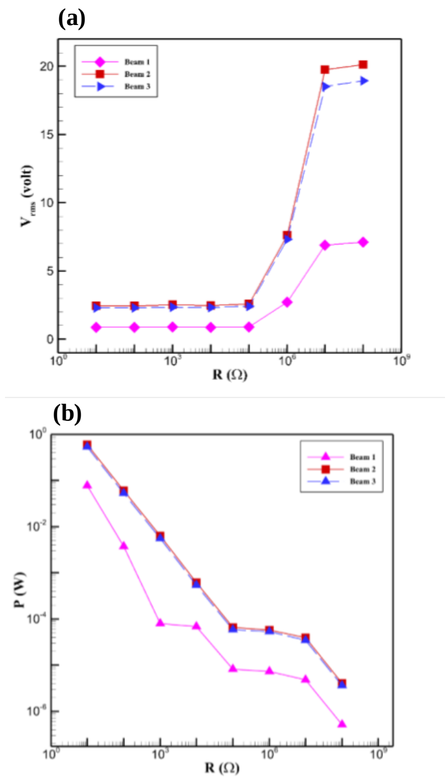

Figure 3. Variations of the, (a) voltage, (b) power output with electrical resistance in parallel arrangement of three beams

5. Conclusions

The results of this study indicate:

1- In the parallel arrangement, due to stronger vortex interaction and delayed separation of the flow, the vortex shedding frequency is greater compared to triangular and single-beam arrangements, and it has been shown that the presence of gap plates at the downstream of the circular cylinder reduces vortex shedding from the cylinder.

2- In short circuit condition, the amplitude of oscillations and the value of the frequency are low and they increase continuously with increasing resistance, with maximum amplitude and frequency occurring at 1000 Ω resistance, and their minimum values occur in open circuit conditions, and in the parallel arrangement, the total average amplitude of beams oscillations is higher than the other two arrangements.

3- With an increase in electrical resistance, the generated voltage increases significantly, and the maximum voltage is obtained at 100 MΩ resistance. While the maximum power is obtained at low values of electrical resistance.

4- In the parallel arrangement, the total average amplitude of oscillations, voltages, and electrical power is higher than the other two arrangements, and in both parallel and triangular arrangements, upper and lower beams deliver more power compared to the middle beam output, due to increased interaction between the beams and vortices, and the enhancement of fluid flow kinetic energy by the middle beam acting as a bluff body.

6. References

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