Numerical Simulation of Induced Vibrations Due to Low Frequency Flow Oscillations around Piezoelectric Blades to Design the Best Configuration for Energy Harvesting

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ABSTRACT

One of the most important issues facing today's society is the issue of energy production and the challenges surrounding it. For this reason, it is very important to address the issue of energy harvesting from various methods. One of these methods is energy harvesting from vibrations caused by fluid flow. Vibrations generated by the incompressible air fluid flow around three parallel piezoelectric blades behind a circular cylinder at different longitudinal distances can be one of the best options for examining and evaluating the amount of electrical voltage generated by piezoelectric blade vibrations. According to this study, a situation in which the middle piezoelectric blade is shifted by half the length of the blade to the right and the direction of the clamp is opposite to the direction of the clamp of the up and down blades is the optimal structure for voltage output and reducing collision probability. Due to the reduced probability of the blades colliding with each other in this optimal case, the maximum Reynolds number without the blades colliding increased from 2400 in non-optimal structures to 2600 in the optimal structure, which increased the voltage output in the middle blade by 12% and about 14% for up and down blades.

KEYWORDS

Computational fluid dynamics, Energy harvesting, Fluid-Structure Interaction, Piezoelectric blades, Low frequency oscillations

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1. Introduction

With the growing population and the development of various industries, the need to supply the energy they need has become more apparent. As oil and gas resources, as well as other types of fossil fuels, are depleted, finding a variety of innovative ways to obtain energy is a challenge for the world. One of these methods is energy harvesting through vibrations with the help of piezoelectric plates. This vibration can be caused by the oscillating current of a fluid. In this method, a fluid such as air flows around one or more piezoelectric plates, and vibrations from the fluid flow cause the plate to move. These plates have the ability to convert mechanical forces into electricity and in this regard are one of the new methods of energy extraction.

Many researchers have done research in the field of energy harvesting by vibrating piezoelectric plates. Taylor et al. Developed an eel structure of the piezoelectric polymer to convert mechanical flow energy into electrical force. They focused on describing and optimizing the eel system with production and storage units in the wave tank and reported their results to advance future research [1]. Pobering and Schwesinger made an attempt to analyze the vortices created by objects to demonstrate the ability of vortex vibrations to absorb the energy around flexible piezoelectric beams [2]. In another study conducted experimentally by Mutsuda et al., A piezoelectric plate composed of various layers was placed vertically inside the chamber water flowed. The results were obtained for beams in different thicknesses and showed a good agreement with the simulation results in the output voltage [3]. Min Liu et al. Also conducted an experimental study to capture energy underwater by the mechanism of induced vibrations and concluded that the vibration frequency, amplitude, and average power increase with limited water velocity. [4].

In this study, the use of multi-blade piezoelectric blades under the influence of low-frequency fluid flow has been considered. Such an issue has been less addressed in previous studies and clearly the structure of the present study has not been addressed. Due to the fact that low-frequency oscillations can't provide the appropriate force range for vibration and energy harvesting, piezoelectric blades are designed to vibrate at low-frequency oscillations and ultimately study the optimal structure for energy harvesting and voltage output is another issue that is addressed in this study.

2. Governing equations

In order to simulate the oscillations of the piezoelectric blade, the UDF code based on rewritten equation of mass, spring and damper has been used. The equation is as follows:

$$m\ddot{y}_t + c\dot{y}_t + (k + \frac{\theta^2}{C})y_t = F \qquad (1)$$

Where y_t is the displacement of the blade tip, m is the mass, c is the damping coefficient and k is the spring stiffness. Also, F is the force on the piezoelectric blade, C Capacity and θ is electromechanical coupling coefficient. For more details about the equations check reference [5] and for the parameter values check reference [6].

3. Problem definition and numerical solution method

In the present study, in order to solve the governing equations of the piezoelectric fluid and blades, a numerical solution based on simulation using Fluent software has been used. In this study, in order to discretize the equations related to fluid motion, the simple algorithm has been used. For the pressure equation, the second-order discretization method is used. In order to separate derivative expressions, the second-order upwind method is used.

This study has been investigated in four general cases in terms of blade placement and their oscillation direction at Re 2300(B11, B12, B21, B22). Finally, a case at a higher Reynolds number is defined in order to find the optimal case (B23: B21 at $\mathrm{Re} = 2600$). The structure of these cases is shown in Figure 1. The D value in this figure is 0.03 m.

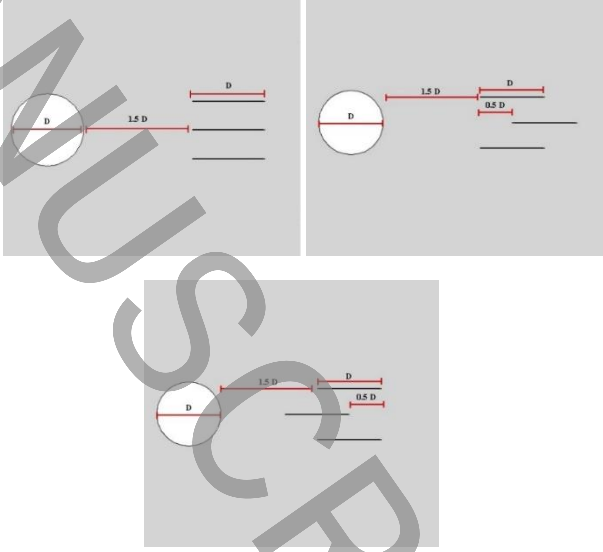

Figure 1. Geometry of B11 and B12 cases (top left), B21 case (top right), B22 case (bottom).

4. Results

The comparison of the output voltage of the studied cases in Reynolds number 2350 is done according to table (1). According to this table, the amount of output voltage in B12 case for the middle blade is the highest, and not too far after that case is B21. For the upper and lower blades, due to their asymmetric oscillation, the maximum amount of voltage generated occurs only in one of the upper or lower limits in the B12 and B21 cases, respectively.

Table 1. Comparison between the output voltage for all cases at Reynolds number of 2350. (Volt)

	Upper blade	Middle blade	Lower blade
B11	-1.5 to 2	±2	-2 to 1.5
B12	-0.5 to 3.1	±4.2	-3.1 to 0.5
B21	-2.75 to 1.1	±3.2	-1.1 to 2.75
B22	-1.9 to 2.1	±0.9	-2.1 to 1.9

Another topic discussed in this study is finding the best structure in which the blades do not collide with each other as much as possible. According to the results, the B21 case of the structure was identified, in which the Reynolds number up to 2600 could be increased without the blades colliding with each other (B23 case). The figure 2 shows the vorticity magnitude contour for B21 case in Re 2600(B23 case).

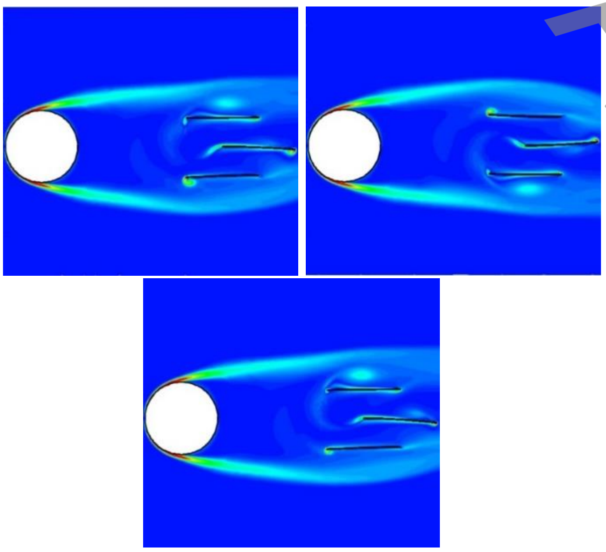

Figure 2. Vorticity magnitude contour over cylinder and three blades at 1.68s(up left), 1.76s(up right) and 1.84s(bottom) for B23 case.

5. Conclusions

In the present study, the energy harvesting from the oscillations of three piezoelectric blades behind a stationary cylinder in various structures at Reynolds number 2350 was investigated. Preliminary studies also showed a limit on increasing the Reynolds number (input speed) to prevent the upper and lower blades from colliding with the middle blade, which provided a new structure to improve this limitation. According to the results of this study, the two "B12" and "B21" cases had the best structure for energy harvesting, respectively. However, in the first case, there was a limit on increasing the Reynolds number due to the possibility of the upper and lower blades colliding with the middle blade up to a maximum of 2400 Reynolds number, but in B21 case, this limit increased to 2600 Reynolds number (B23 case), by 8%. Also, this increase was calculated to be about 12% for the voltage range of the middle blade and about 14% for the upper and lower blades. Another issue that was compared in all cases was the dominant oscillation frequency of the blades, according to which each blade may oscillate at different frequencies, but the dominant oscillation frequency of all blades was observed to be the same for a particular case. It should be noted that this predominant value for all cases has changed from 5 to 6 Hz, which is considered a low frequency compared to the natural frequency of each blade (25.64 Hz).

6. References

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