Design and optimization of a flapping water flow energy harvester

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Abstract. This paper reports a flapping water flow energy harvester. It consists of a bluff body and a cantilever based resonator. The bluff body facing the water flow creates mechanical instability. The bluff body can control forces and pressures applied to the tip of the resonator, i.e. a wing, so a continuous and stable oscillations of the resonator can be achieved. Key parameters for initiating and maintaining such oscillation include position and size of the bluff body as well as the angle of attack. These parameters were simulated in ANSYS and simulation results were verified experimentally. In order to test the energy harvesting capability of this structure in water, a MFC patch was attached to the cantilever and output power was measured when the harvester was placed in laminar water flow with the speed of 1 m/s. A maximum power of 52 \textmu W was recorded.

1. Introduction

Energy harvesting concerns methods to obtain energy from ambient resources such as vibrations, heat, water and wind. It is regarded as a promising energy source to power small electronic devices, e.g. wireless sensors. It is most suitable for applications where maintenance is difficult and costly. Monitoring using wireless sensors in water industry is challenging because the size of water networks is vast and a majority of water pipes are buried underground. There is an increasing demand to innovate the existing water networks to enable maintenance free wireless monitoring. A reliable power source is essential for these wireless sensors. The work reported in this paper focused on methods to harvest energy from water flow.

Some work on energy harvesting from water flow has been reported. Both piezoelectric and electromagnetic transducers have been considered to convert water flow into electrical energy. Wang \textit{et al} [1] developed a piezoelectric energy harvester which generated electrical energy from oscillation caused by the Kármán vortex street behind a bluff body in a water flow. However, the output power was only 0.7 nW in water flow of 1 m/s. Water flow energy harvesters based on electromagnetic transducers have also been reported [2, 3]. However, existing devices are all propeller based and harvest energy from rotation. Such devices require regular maintenance to keep the bearing lubricated and extend its life time. The device presented in this paper operates based on the flapping oscillation of a cantilever structure flow and thus has longer lifespan. It is mitigated from a device initially designed for air flow application [4]. Some key parameters were optimized using ANSYS CFD and initial experimental results of its energy harvesting capability in water are reported.
2. Operation principle, simulation and device prototyping

2.1. Principle

The water flow energy harvester presented here evolves from a previously reported air flow energy harvester based on flapping operation principle, as shown in Figure 1, to convert flow into mechanical oscillation to harvest energy [4]. The device consists of a bluff body in charge to create responsible for creating mechanical instability and a cantilever based resonator. The bluff body can control forces and pressures applied to the wings so a continuous and stable oscillations of the resonator can be achieved. One of the ends of the of the cantilever beams is anchored while the other hold a wing. Previous study showed that the position and size of the bluff body as well as the angle of attack (α) in Figure 2) have significant effect on the performance of this flapping structure.

![Figure 1. Basic operational Principle of the flapping energy harvester.](image1)

![Figure 2. Schematic of the testing prototype of the flapping energy harvester.](image2)

2.2. Simulation

ANSYS simulations has been carried out to maximize the lifting force by varying positions and sizes of the bluff body as well as the angle of attack. Figures 3 and 4 show simulated pressure difference between top and bottom of the wing tip. This also gives an indication of the lift force applied to the wing. The higher the pressure difference there is, the larger lifting force is applied to the wing. Simulation results in Figure 3 showed that when α is 45°, the pressure difference between top and bottom of the wing tip became maximal which means the maximum lift force can be achieved at such degree. In addition, simulation results also show that when the bluff body position is placed 10 mm to the edge of the wing tip, the maximum pressure difference, thus, maximum lifting force, can be achieved as shown in Figure 4. As shown in Figure 5, such combination is able to provide a pressure difference of 1931 Pa. Given the wing tip area of 0.00385 m², the maximum lift force is 7.4 N. Such a force can initiate a constant oscillation with a maximum displacement of 50 mm.

![Figure 3. Various angles of attack shows provide different pressure values. 45° is shown as the optimum degree.](image3)

![Figure 4. Distance from bluff body to the wing tip gives different pressure values.](image4)
2.3. Prototyping
In order to verify the simulation results in ANSYS, a prototype with adjustment capability on the bluff body and angle of attack was fabricated as shown in Figure 6. The base, bluff body and wing were all 3D-printed using PLA. The cantilever beam was made of 0.3 mm thick Beryllium Copper (BeCu) due to its excellent mechanical properties. In order to test the energy harvesting capability of this structure in water, a MFC [5] strip is attached to the cantilever beam as a transducer to convert mechanical oscillation into electrical energy as shown in Figure 7. The MFC strip generates an electrical signal when the mechanical stress is applied.

3. Tests and Results
The prototype was tested in a hydraulic channel under the water flow with a speed of 1 m/s. It was measured that due to the existence of the bluff body, the speed of the water stream that meets the wing tip was doubled to 2 m/s. As the channel is made of steel, the prototype was anchored to the bottom of the channel using strong magnets. The device was located in the centre of the water flow path.

First test was carried out to find the optimum location of the bluff body and the angle of attack. It was found that when the angle of attack is around 45 and the bluff body is around 10 mm away from the wing tip, stable oscillation of 0.9 Hz with a maximum displacement of 5 cm occurred. This matches the simulation results presented earlier. This setting was kept for the remaining tests.

The MFC was connected to various resistive loads while its output voltage was measured. Thus, the output power can be calculated and optimum load resistance can be observed. Figure 8 shows the experimental results of output power when the harvester was connected to various load resistance. The optimum load resistor was found to be 3 MΩ while the maximum output power was measured as 52 µW.
4. Conclusion
In this paper, a flapping energy harvester capable of harvesting energy from water flow was studied. The structure was modelled in ANSYS and a prototype device was fabricated and tested to verify simulation results. It was found that the position and size of the bluff body and angle of attack have significant effect on the performance of such flapping energy harvesters. These key parameters were optimized in ANSYS to achieve the maximum lift force and oscillation displacement. By attaching a MFC patch to the cantilever beam, electrical energy can be generated while the beam is oscillating.

Although the study demonstrated the feasibility of using this structure for energy harvesting from water flow, the measured output power is relatively low. One of the reasons is that the resulting oscillation has a very low frequency (0.9 Hz) and the piezoelectric transducer is not particularly efficient in this frequency range. Further work will be done to implement methods to up-convert the operating frequency of this structure if piezoelectric transducer is still considered or to adopt electromagnetic transducers which works much better at lower frequencies.

5. References
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Acknowledgments
Jorge Antonio Nieves Juárez would like to acknowledge the financial support from the Consejo Estatal de Ciencia y Tecnología del Estado de Queretaro and the Technical University of Queretaro to complete his internship at the University of Exeter.