Micro magnetic driven bidirectional turbine used in urban water mains for hydropower generation

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ABSTRACT

Relaible electric power supply pays an important role for water supply performance minitoring systems along water supply pipelines. Micro hydropower harvesting from water pipes provides a promising and cost-effective solution for power supply to water monitoring systems. However, bidirectional flow may exist in the water mains when switching supply sources for the particular District Metering Area (DMA), so it is necessary to develop a bidirectional turbine. In this paper, a micro magnetic driven bidirectional cross-flow turbine is developed. A cross-flow runner is inserted into the water supply mains through a T-joint, two blocks are integrated to the pipe inner wall on the upstream and downstream side of the runner to direct more water to flow through the runner. Besides, a magnetic coupling is used in the turbine to replace traditional mechanical seal so that seal failure can be avoided. The developed turbine can operate in bidirectional water flow without changing the rotation direction of the runner.

Keywords: bidirection cross-flow turbine, magnetic coupling, water mains, micro hydropower harvesting

1 INTRODUCTION

In Hong Kong, more than 8000 km water mains are laid underground to supply water for over 7 million populations. However, a considerable length of water mains has approached the end of their service life in the 1990s and the deterioration of water mains may result in severe water leakage [1]. It is estimated that nearly 15% of fresh water was wasted in 2016 due to pipe leakage [1]. Therefore, the Water Intelligent Network (WIN) is used by the Water Supplies Department of Hong Kong for timely detection and early warning of water leakage. The WIN achieves its function using large amount of monitoring and sensing equipment which is installed in the network and usually powered by traditional batteries. However, traditional batteries usually have limited lifespans even with efficient energy conserving mechanisms [2]. Once the batteries ran out, the WIN would die, so the batteries need to be replaced frequently, resulting in a high cost and a huge demand for labor [3]. As water flow inside the water pipes is constant and the water head is usually excess, micro hydropower harvesting from water pipes provides a promising and cost-effective solution for power supply to water monitoring system. However, unlike traditional micro hydropower, the water mains possess a very high requirement for hydropower harvesting because of water security and complex pipe conditions. Firstly, no water pollution or leakage could be caused by the application of inline turbine. To meet this requirement, all the components that contact with water are made of food grade materials. Besides, a magnetic coupling is used for sealing and transmission. Unlike traditional mechanical seal which achieve sealing by tight fit of two different seal parts, the magnetic coupling seals water by a containment shroud and transfers torque from one shaft to another using a magnetic field rather than a physical mechanical connection, so seal failure and water pollution can be avoided effectively. Secondly, bidirectional water flow may exist in the water mains under the situation of pipe bursting for maintenance or switching of supply sources, so the inline hydro turbine should be capable to generate electricity with bidirectional water flow.

In this paper, a micro magnetic driven bidirectional hydro turbine is developed to generate electricity using limited water head inside water mains.

2 TURBINE DESIGN

Figure 1 shows the main structure of the developed bidirectional turbine. The inline turbine consists of a T-joint, two blocks integrated to the pipe inner wall and one cross-flow runner inserted through the T-joint. Besides, a 24V generator is located on the top of the turbine and connected to the runner through coupling, shaft and magnetic coupling. The blocks are used to accelerate flow velocity and direct more water to flow through the runner, so that the runner can harvest energy from water flow and transfer the energy into electricity.

Figure 2 shows the cross-sectional view of the turbine and indicate the working principle of the proposed bidirectional turbine. To apply in bidirectional flow, the shape of blocks integrated to pipe inner wall is specially designed. Each block consists of a plane surface and a curved surface. The function of the plane surface is to direct the water flow while the curved surface can force the water to flow towards the runner gradually. With the developed blocks, the inline turbine could operate under bidirectional water flow without changing the runner rotation direction.

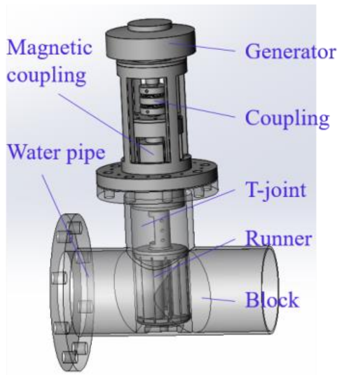

Figure 1: Schematic diagram of the bidectional turbine.

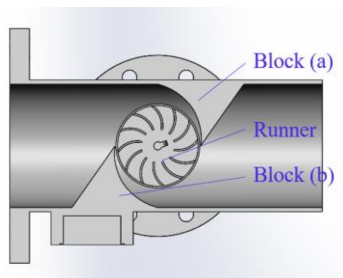

Figure 2: Working principle of the bidectional turbine.

In traditional micro turbines, mechanical seals are often used in the space between turbine body and shaft to avoid leakage. However, the mechanical seals achieve sealing by tight fit of two different seal parts, the friction caused by sliding of two surfaces against each another may results in a significant mechanical loss, furthermore, the mechanical seals would eventually wear out and fail. So in this project, a micro cross-flow turbine with magnetic coupling is developed.

A magnetic coupling is a coupling that transfers torque from one shaft, but using a magnetic field rather than a physical mechanical connection. Figure 3 shows the working principle of a magnetic coupling, which consists of external coupling half, internal coupling half and a containment shroud. The external coupling half and internal coupling half are made of permanent magnet and they are separated by the containment shroud, which means that they do not connect to each other. As the magnetic coupling transfers torque by magnetic force, there is no friction between the external coupling half and internal coupling half. The internal coupling half is coverd by 316L stainless steel shell and thecontainment shroud is made of 316L stainless steel to avoid negative effects on the water quality. As the external coupling half does not contact with water, it is made of carbon steel to reduce costs.

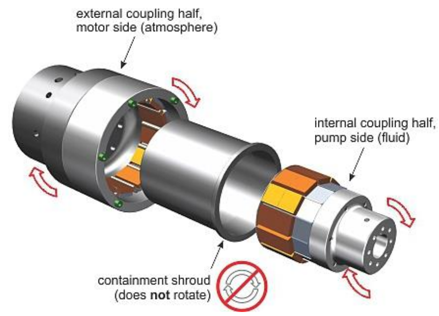

Figure 3: Working principle of magnetic coupling [4].

3 EXPERIMENTAL STUDY

Figure 4 indicates the prototype of the bidirectional turbine. Figure 4(a) shows the water tube and the block while Figure 4(b) illustrates the runner and the transmission assembly. The runner is made of 12 blades, which are welded to 2 discs. in addition, a runner holder is located on the bottom of the turbine body to hold the terminal of the runner to reduce runner deformation.

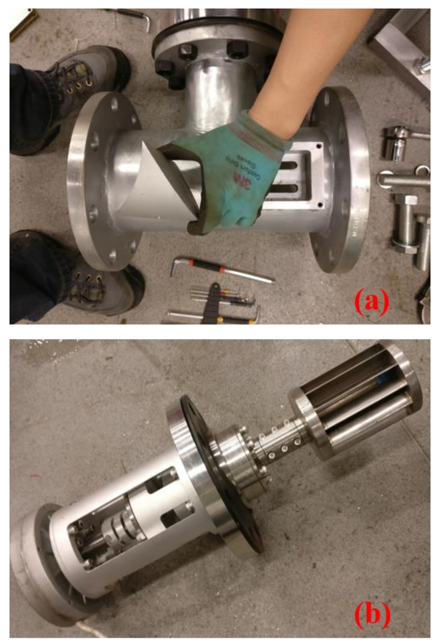

Figure 4: Prototype of the bidirectional turbine.

The prototype is tested in the hydraulic test rig built by the Renewable Energy Research Group of the Hong Kong Polytechnic University. Figure 5 shows the hydraulic test rig which is composed of two centrifugal pumps, a water tank, flow meter, presure sensors, ball valves and the monitoring computer. The centrifugal pumps are controlled by a frequency converter controller. By adjusting the frequency converter controller and the opening degree of the ball valve, the flow velocity can be adjusted from 1 to 3.0m/s and the maximum water head can reach 40m water. The pressure sensors and electromagnetic flow meter are used to detect water head and flow velocity, respectively. A

24V three-phase permanent magnet alternating generator with low starting torque is connected to the turbine shaft for electricity generation. A controller was developed for power management and data collection and the monitored water head, flow velocity, turbine rotation speed, charging voltage and current can be recorded in the computer.

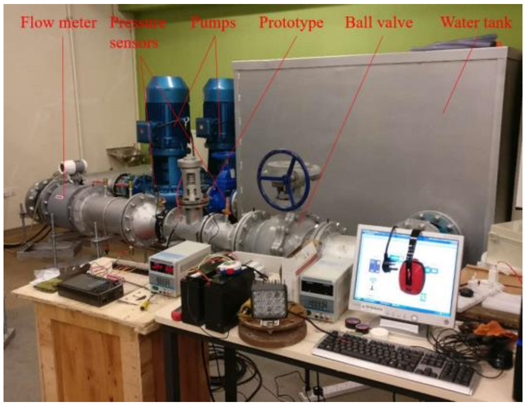

Figure 5: Lab hydraulic tset rig.

4 RESULTS AND DISCUSSION

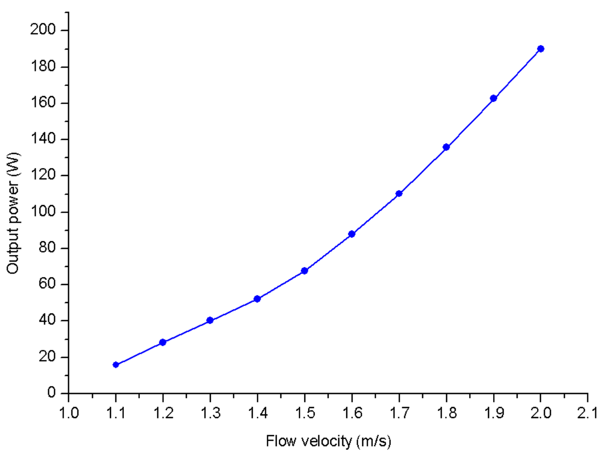

Figure 6: Power output of the turbine.

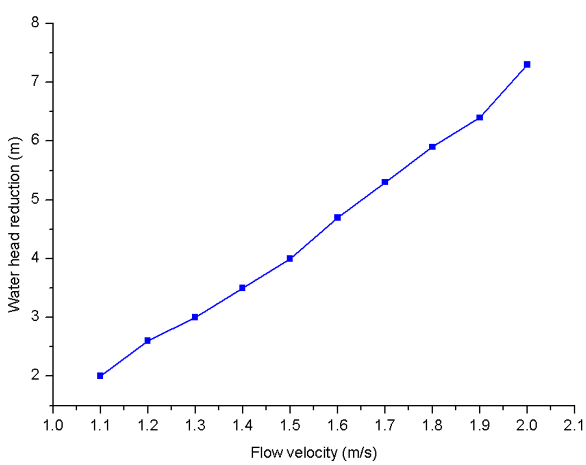

Figure 7: Power output of the turbine.

After a series of lab tests, the performance of the proposed bidirectional inline turbine is obtained. Figure 6 and 7 show the experimental output power and water head reduction, respectively. As can be seen in the figures, both of the output power and water head reduction of the turbine increase with the increment of flow velocity. At 1.5m/s, which is the design flow velocity in this project, the output power is 67W while the water head reduction is 4m water. When the flow velocity increases to 2m/s, the output power reaches 190W with 7m water head reduced.

5 CONCLUSION

To supply reliable power to water monitoring systems along water supply pipelines, a magnetic driven bidirectional micro inline hydro turbine is reported in this paper. In the proposed turbine, the block shape is specially designed to satisfy the working condition of the bidirectional flow. Besides, a magnetic coupling which transmits torque using magnetic field is adopted to avoid leakage and to reduce mechaniocal loss. The lab tests have demonstrated that the developed turbine performed very well, which means the turbine can be used in bidirectional flow. At the design point, the turbine can generate 67W power with 4m water head reduced.

ACKNOWLEDGEMENT

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