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Power Generation from Sewage by a Micro-Hydraulic Turbine

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***Abstract*—**This study is concerned with the development of a micro-hydraulic turbine for power generation installed in sewer pipes. The runner has a circular hollow around the central (rotating) axis so that solid materials included in water can be easily flow through the runner without blocking the turbine. The laboratory experiments are also conducted. The hollow is very effective to make polyester fibers pass through the turbine. The guide vane is useful to heighten the turbine performance. But it is easily blocked by the fibers, making the turbine lose the function.

***Keywords*—**Generation of electricity, micro-hydraulic turbine, sewage, sewer pipe.

I. Introduction

HYDROPOWER is converted to electric energy through hydraulic turbines. The spread of micro-hydropower generation is being expected with the background of a public opinion promoting the use of renewable energy. The micro-hydraulic turbines, which are installed in small rivers and agricultural canals, have been developed [1]-[6]. Their output power is less than 1 kW. Reference [7] performed a numerical simulation of the flow through a nano-hydraulic turbine of impulse-type driven by waterfalls of extra-low head [4]. Reference [8] also conducted a numerical simulation of the flow through an open type cross-flow runner of a nano-hydraulic turbine driven by rapid and shallow stream [5].

Sewer pipes have a considerably high potential of hydropower, because they are spread all over the cities. If micro-hydraulic turbines are successfully driven with the sewage, they realize the small-scale distributed power generation as well as contribute the local production for local consumption of electric power. Sewages are generally composed of water and solids. The existing micro-hydraulic turbines for small rivers and agricultural canals are originally developed to be driven by water including no solids. Therefore, if the existing micro-hydraulic turbines are installed in sewer pipes, they are blocked by the solids and eventually lose their function.

In this study, a micro-hydraulic turbine, which can be installed in sewer pipes, is developed. The turbine successfully generates the electric energy from the sewage without being blocked by the solids in the sewage. The turbine performance and the passage of polyester fibers are also investigated by the laboratory experiment to demonstrate the applicability of the turbine to sewer pipes.

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II. Experimental

A. Experimental Setup

Fig. 1 shows the cross-section of the micro-hydraulic turbine developed in this study. A rotational circular pipe hatched with red (diameter 80 mm, length 195 mm) is inserted between two stationary pipes of diameter 80 mm. Their axes are on a line. The inserted pipe is supported by two bearings at both ends so that it can rotate around the central axis. A runner with four blades is mounted inside the inserted pipe. The inserted pipe and the runner rotate integrally by the water flowing in the pipe. Consequently, the hydraulic turbine has no shaft rotating the blades. The rotational motion is transmitted to a generator, which is set outside the pipe, through a belt. A guide vane is also mounted at the end of the stationary pipe just upstream of the rotational pipe.

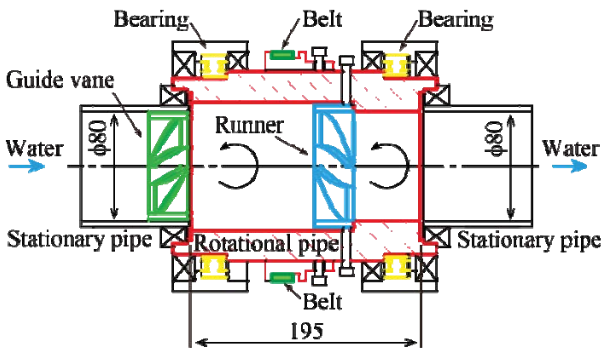

Fig. 1 Cross-section of micro-hydraulic turbine

Fig. 2 shows an example of the runner. A circular hollow is provided around the rotating (central) axis so that solid materials included in the water could pass easily through the hollow without blocking the turbine. The ratio for the hollow diameter D_2 to the pipe diameter D_1 (=80 mm) is defined as the hollow ratio D_2/D_1.

An example of the guide vane is shown in Fig. 3. A hollow having the same diameter as that of the runner is also provided around the central axis of the guide vane.

A cut model of the micro-hydraulic turbine is shown in Fig. 4. The runner rotates with the outer circular pipe around the pipe axis by the water flow. The rotational motion drives a generator or a torque meter through the belt.

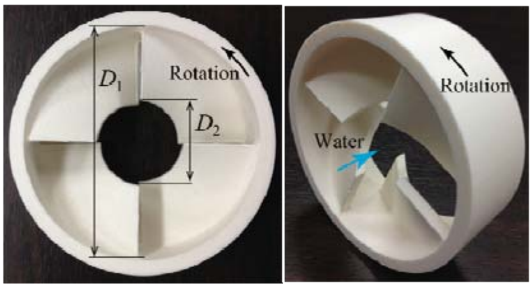

Fig. 2 Runner with hollow ratio of D_2/D_1=0.375

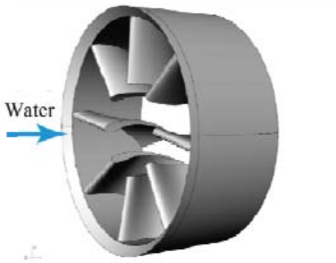

Fig. 3 Guide vane with hollow ratio of D_2/D_1=0.375

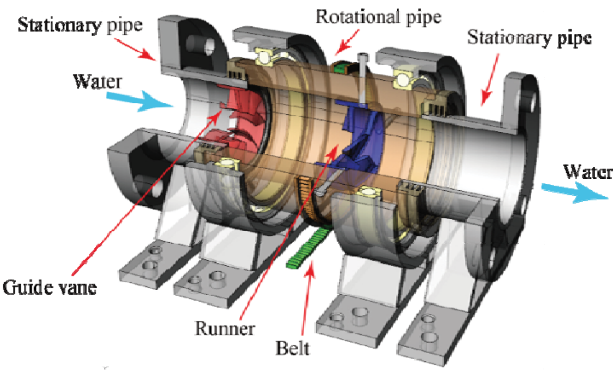

Fig. 4 Cut model of micro-hydraulic turbine

To investigate the turbine performance, a laboratory experiment is conducted by using a closed-loop test ring shown in Fig. 5. Water in a tank is circulated by a pump. The flow rate is measured by a flowmeter of propeller type mounted in a bypass pipe upstream of the turbine. The pressures at two points just upstream and downstream of the turbine are also measured. To detect the output of the turbine, the torque is measured by a torque meter driven by the turbine. The rotational speed of the turbine is controlled by a powder brake connected with the torque meter.

The turbine efficiency η is defined as:

$$\eta = \frac{T\omega}{Q(P_1 - P_2)} \qquad (1)$$

where T is the torque, ω is the angular velocity of the turbine, Q is the flow rate, P_1 and P_2 are the pressures at the positions upstream and downstream of the turbine, respectively.

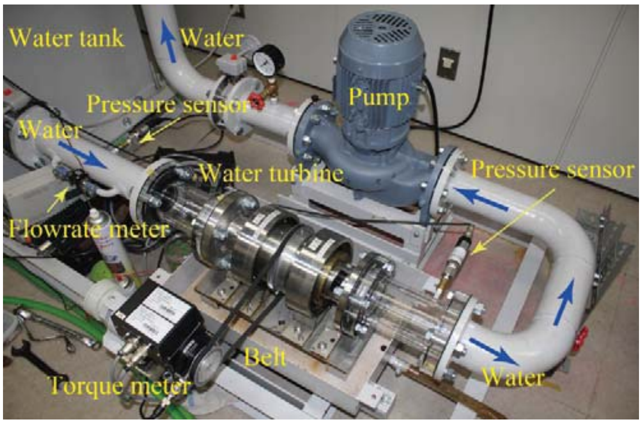

Fig. 5 Experimental setup

B. Passage of Polyester Fibers through Turbine

Polyester fibers are entrained into the turbine in the laboratory experiment so as to simulate the entrainment of solid materials involved in sewer pipes. Spherically-shaped fibers with diameter of 30 mm, 50 mm and 70 mm are entrained into the water flow at the outlet pipe of the water tank. Fig. 6 shows the fibers. After the experiment, the turbine is disjointed to observe the fibers attaching to the guide vane and the runner.

Fig. 6 Spherically-shaped polyester fibers

The water passing through the turbine returns to the tank. Thus, the fibers flowing with the water can be caught at the entrance of the tank by a net. The passage ratio of the fibers ξ is defined as:

$$\xi = m_1 / m_2 \qquad (2)$$

where m_1 is the mass of the fibers caught at the tank and m_2 is the mass of the fibers entrained into the water flow upstream of the turbine.

C. Experimental Conditions

The water flow rate Q is 0.01 m^3/s. The cases of the hollow ratio D_2/D_1 of 0, 0.25, and 0.375 are investigated. The effect of the guide vane is also studied.

III. Results and Discussions

A. Turbine Efficiency

The relation between the turbine efficiency η and the rotational speed N [rpm] is shown in Fig. 7. The result for the runner without the hollow (D_2/D_1=0) is shown in the top graph of Fig. 7. When using the guide vane, the maximum efficiency η_{max} is 0.174. When the guide vane is not employed, the maximum efficiency η_{max} is 0.1. One can confirm that the guide vane heightens the efficiency. The middle graph of Fig. 7 shows the result for the runner of D_2/D_1=0.25. The effect of the guide vane appears even for the runner having the hollow around the central axis of the runner. The efficiency reduces markedly when D_2/D_1=0.375 as found from the bottom graph of Fig. 7. The guide vane still has the ability increasing the efficiency. The maximum efficiency η_{max} is 0.116 when employing the guide vane. It is the 67% of that for the runner without the hollow (D_2/D_1=0). This is because the energy of the water is less converted to the rotating motion of the turbine due to the reduction of the blade area of the runner. It should also be noted that the rotational speed N decreases with increasing the hollow ratio D_2/D_1.

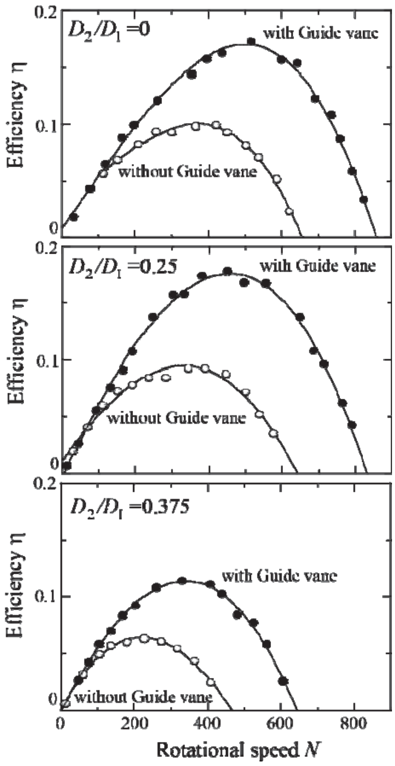

Fig. 7 Relation between rotational speed and turbine efficiency

Fig. 8 rearranges the relation between η and N by using the parameter D_2/D_1. The top graph of Fig. 8 shows the result when employing the guide vane. The efficiency of the runner of D_2/D_1=0.25 is almost the same as that of the runner of D_2/D_1=0. The hollow ratio D_2/D_1 less affects the efficiency. The rotational speed lowers with increasing D_2/D_1. The efficiency for the runner having the larger hollow ratio (D_2/D_1=0.375) is lower. It is about half of the efficiency for the runner of D_2/D_1 =0. The bottom graph of Fig. 8 shows the result when the guide vane is not employed. The effect of the hollow ratio on the efficiency is almost the same as that when employing the guide vane.

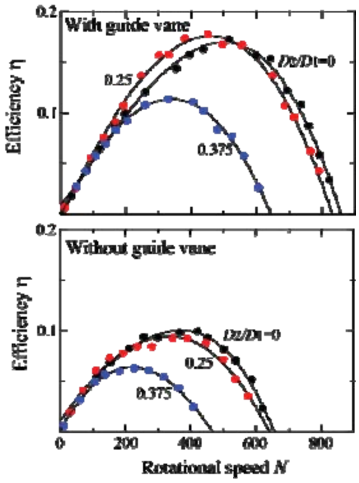

Fig. 8 Effect of hollow ratio on turbine efficiency

B. Passage of Polyester Fibers

The passage ratio of the fiber ξ is listed in Table I. When employing the guide vane, the passage ratio for the runner of D_2/D_1=0 is extremely low (ξ=0.14). But the ξ value heightens with increasing D_2/D_1. The value for the runner of D_2/D_1=0.375 is 0.9. When the guide vane is not employed, the passage ratio for the runner of D_2/D_1=0 is still low ($\xi = 0.3$). But the ξ value is high for the runner of $D_2/D_1 \geq 0.25$.

TABLE I
Passage Ratio of Fibers ξ

	Hollow ratio D_2/D_1		
	0	0.25	0.375
With guide vane	0.14	0.15	0.9
Without guide vane	0.3	0.95	1

TABLE II
Change in Turbine Behavior Due to Fibers

	Hollow ratio D_2/D_1		
	0	0.25	0.375
With guide vane	Breakdown	Breakdown	Unchanged
Without guide vane	Breakdown	Unchanged	Unchanged

Table II lists the change in the turbine behavior due to the entrained fibers. It is found that the turbine with the guide vane maintains the function only when D_2/D_1=0.375. If the guide vane is not employed, the turbine is less affected by the fibers when $D_2/D_1 \geq 0.25$. Though the guide vane heightens the turbine efficiency as shown in Figs. 7 and 8, it lowers the passage ratio of the fibers as listed in Table II. The passage of the fibers is described in the following six paragraphs.

Fig. 9 shows the photograph of the guide vane placed upstream of the runner of D_2/D_1=0.375. The fibers are attached to the guide vane. But they are not attached to the runner, though their depiction is omitted. The deterioration of the turbine performance is not observed as listed in Table II.

Fig. 10 shows the photograph of the runner of D_2/D_1=0.375 when the guide vane is not employed. As the passage ratio ξ is 1, no fibers are attached to the runner. The runner perfectly maintains the function.

Fig. 9 Guide vane of D_2/D_1=0.375

Fig. 10 Runner of D_2/D_1=0.375

Fig. 11 Guide vane and runner of D_2/D_1=0.25

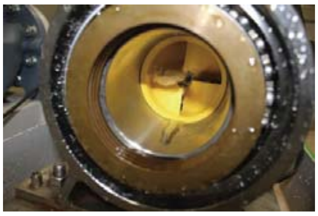

Fig. 12 Runner of D_2/D_1=0.25

The photographs of the guide vane and runner of D_2/D_1=0.25 are shown in Fig. 11, where ξ=0.15. The fibers are trapped only by the guide vane. Due to such blockage of the guide vane, the turbine does not maintain the rotation as listed in Table II.

Fig. 12 shows the photograph of the runner of D_2/D_1=0.25 when the guide vane is not employed. The ξ value is 0.95. A few fibers are attached to the runner. The turbine performance remains unaltered.

Fig. 13 shows the photographs of the guide vane and runner of D_2/D_1=0. The ξ value is 0.14. The fibers are attached to the guide vane and the runner. The turbine loses its function by the attached fibers.

The photograph of the runner of D_2/D_1=0 is shown in Fig. 14, where the guide vane is not employed. The ξ value is 0.3. The runner is blocked by the fibers, and therefore it loses the function.

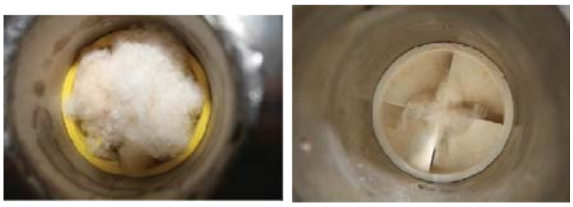

Fig. 13 Guide vane and runner of D_2/D_1=0

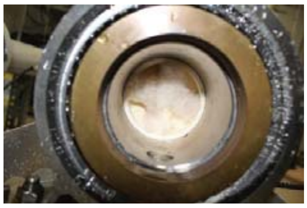

Fig. 14 Runner of D_2/D_1=0

IV. Conclusions

A micro-hydraulic turbine having a circular hollow around the central axis of the runner is developed. The turbine performance and the passage of polyester fibers are investigated by laboratory experiments. The results are summarized as follows:

(1) The hollow around the central axis of the runner is very effective to make the fibers pass through the turbine. For the runner of the hollow ratio of 0.375, the passage ratio is higher and the blockage is not caused.

(2) The guide vane is useful to heighten the turbine performance. But it is easily blocked by the fibers, and accordingly the turbine loses its function due to the blockage.

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