

Development turbine blade for ultramicro hydro power generation by 3D printer system

T Kamimura^{1,2}, H Itoh¹ and K Sugiura¹

¹Osaka Prefecture University College of Technology, 26-12 Saiwai-cho, Neyagawa, Osaka 572-8572, Japan

E-mail: kamimura@osaka-pct.ac.jp

Abstract. We have developed micro generation system for effective use of unutilized energy and the spread of a self-controlled dispersion energy supply system. The turbine blade was designed for achieving high performance by special shape. The turbine type was called quasi-Peace turbine type. Turbine with a diameter of 30cm is made of metal, it was created by the 5-axis milling machine. The experimental apparatus was fabricated by the 3D printer. An experiment was carried out in the scale down model. The specific speed of this turbine was much lower than that of existing turbines.

1. Introduction

For global environmental problems are serious, it is desired that a low-carbon society is realized soon. Thus, governments over the world support developing the renewable energy. Since the Great East Japan Earthquake, for the operation of nuclear power generation facilities are stopping, the demand for power generation by the other system has been increasing. Micro-generator apparatus of practical use is not widespread. In Japan, which has many rivers with abundant water because most of the land is occupied by mountains and forests, micro-hydropower system is an effective means. Since it has potential to generate green energy, the development cost is very low and without dam or water storage is needed, the micro hydro turbine technology gives good effectiveness even for unutilized agricultural water way and sand sliding defending dams. The realization of constructing the energy-providing local network, what is called local production for local consumption, will be very robust system against extensive disasters [1,2].

However, to design a high efficient hydraulic turbine is a very complex task, which requires a lot of engineering efforts. In a large-scale development for 1000 KW over class, as profitability can be taken, development specialized for a site is possible. Scale down model experiment technologies are being adopted as effective way for micro turbine design allowing shortening the development time and saving money, instead of the custom fabricate.

In this research, the availability of method by using scale-downed micro turbine model experimental system, whose components are made by 3D printer, is considered, compared with real scale model experimental results. Design time of the turbine by the effective use of 3D printer can be expected to be significantly reduced. This method will make it possible to predict the actual performance without a large-scale experiment.

2. Quasi-peace turbine



2.1. Turbine type

Turbine is the main parts in the micro hydro system, where the task is to convert hydro power to rotational force. Hydro turbine can be classified into two types; namely impulse turbine and reaction turbine. Most of the impulse turbines are suitable for high head and medium head with low flow site. In contrast, a reaction turbine is used for low head site with high flow water, without taking into consideration whether it is horizontal or vertical arrangement. In this study, it is investigated about the quasi-Peace turbine, which is developing for micro hydro system in our laboratory [3]. The circumference of the turbine is filled with water and it is a reaction type.

The turbine is designed that the outer diameter of the turbine of the inlet part so that it can receive the drag of the running water to the maximum. In addition, the exhaust part of the turbine is designed so that the diameter of the turbine becomes small, and achieve high lift from high flow velocity. The turbine should be as small as possible, because the location for using our system is supposed to be narrow space such as a mountain area. From above, by using the newly developed turbine, it is expected to achieve high energy conversion efficiency even in places with low head and small amount of water.

The turbine shape is very complicated because it has conflicting features. We associate turbine shape with tornado phenomenon which encompasses enormous energy. We make full use of the CAD/CAM system to produce the turbine from designed shape. We also use a rapid prototype system that makes rapidly many type models to find out optimal shapes.

2.2. Turbine shape

Turbine modeling is achievement by utilizing 3D-CAD system (Pro/ENGINEER, PTC, Japan). An outline of the turbine assembled in casing by using Pro/ENGINEER is shown in figure 1. Real scale turbine is made of aluminum metal. The shape forming is used with 5-axis milling machine. Milling time is about 24 hours. In the focus of processing time, case of using the milling machine is more than 3D-printer (Mojo, Stratasys, USA) [4].

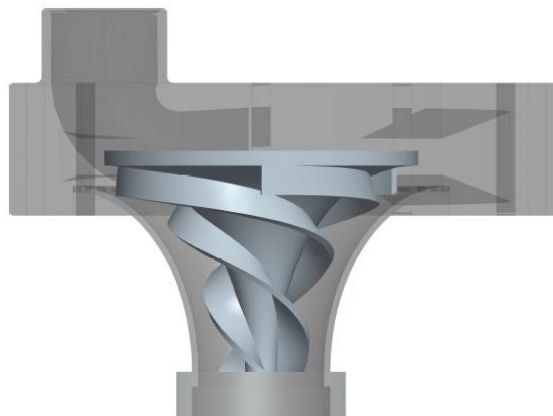


Figure 1. Outline of turbine part by 3D-CAD.

The procedure of modeling by the 3D-CAD is shown, and corresponding figures are shown in figure 2. Figure 3 is a drawing of the developed turbine, D indicates the diameter, and L indicates the height of the turbine.

The modeling procedure is as follows:

- Cylindrical shape whose height is accordance with the turbine's one, is formed by extrude command.
- Ridge line of base part is elliptical arc, which is drawn by sweep command. The arc is quarter of ellipse.
- Twelve virtual planes, is located, which equally divide the cylinder circumferentially by 30

degrees. The arc is also divided into 12. The sketch line segment of blade height is drawn. The angle of the line segment is normal direction of the arc.

- End points of line segments are drawn with smooth curves.
- A number of blades are drawn by copy command.
- Surplus portion of the blade is removed by the cut command.

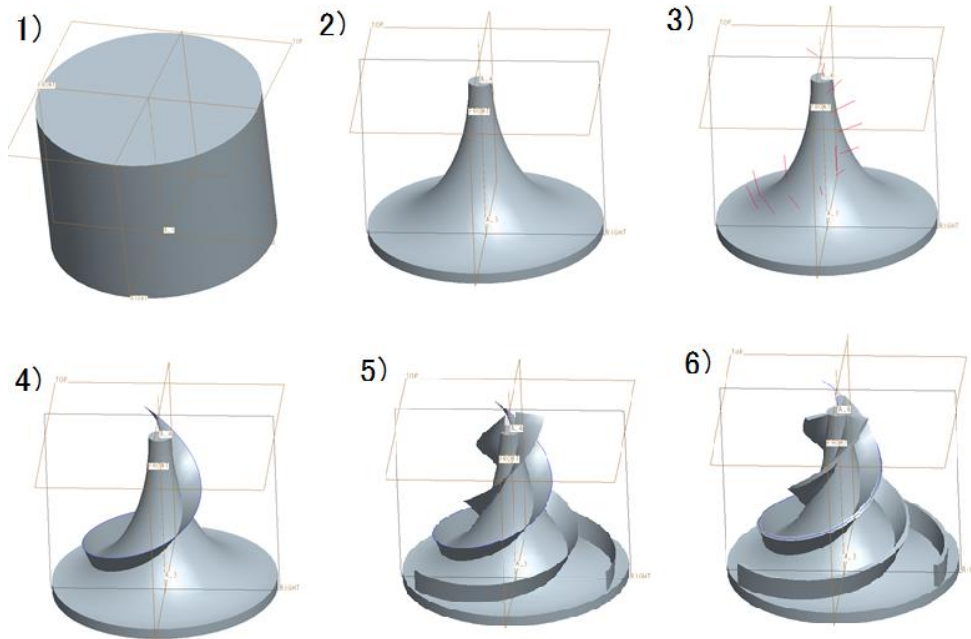


Figure 2. Outline of 3D shape of each feature.

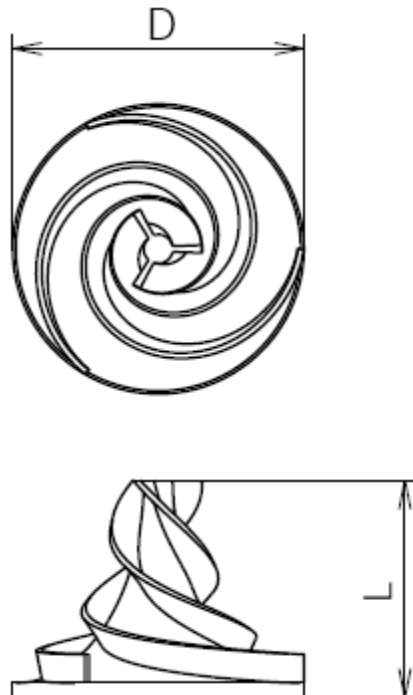


Figure 3. Front and top view of quasi-Peace turbine.

2.3. Scale down model

The development goal is our micro power generation device that achieves about 500 W output at 10 meters gross head. Because of being able to keep running on all day and night, it is assumed that is equivalent to 3 kW class solar power generation unit, which is used for 4 hours a day. The flow rate is desired to be more than 0.005 m³/s. In the head range of 1 m to 10 m, the flow rate range is expected to 0.001 m³/s to 0.01 m³/s. Our study is carried out under the low head and low flow condition [5].

In this study, the developing device is tested in not real field but our laboratory test bench. For restriction of the space, we must experiment under scale down environmental condition. The head of experimental apparatus is adjusted by using the head tank. When we fill the tank, the maximum head is 2.5 m. At the same time, we adjust the manufacturing time and materials cost is less and use scale down model. As a result, the volume of the turbine is very small. The theoretical water power can be obtained by the following equation (1).

$$P_h = \rho g Q H \quad (1)$$

where P_h means Water power [W], ρ means Water density [kg/m³], g means Gravitational acceleration [m/s²], Q means Flow rate [m³/s] and H means Effective head [m].

Since the target of our device is set to 500 W with an actual device level, it is expected that about 7 W calculated from the scale-down model experiment formula will be obtained. The specification of our turbine is shown in table 1.

Table 1. The specification of our turbine.

Parameter	Real Model	Experimental Model
Size D×L	φ300 mm × 225 mm	φ100 mm × 75 mm
Material	Aluminum	Acrylonitrile Butadiene Styrene Resin
Output P	500 W	7 W
(target value)		
Head H	10m	2.5 m

3. Experimental method

Figure 4 shows an overview of experimental setup in this study. The experiment is conducted with using the tap water from tank in our laboratory. The water in the lower tank is pumped up to the upper head tank and falls from bottom of the head tank. A water level of head tank is constant by spilling over. The level is variable parameter. The quasi-Peace turbine installed at the casing part receives the falling water, which rotates the turbine. The flow rate is measured with mounted ultrasound flow meter (FD-Q50C, Keyence, Japan) downstream of the valve. The rotational speed is controlled by loading the rotational axis, which is connected with DC motor and measured by optical tachometer. It is short-circuited by resistance between the terminals of the motor. We use the variable resistance to change a resistance level easily. We can measure the torque by a rotational torque detection device, which is coupled with rotational axis. The shaft power output characteristics are evaluated by measurement of the rotational number and torque of the rotor axis (equation (2)). The measurement is started from stationary condition and torque and rotation number are measured to calculate output as the load are decreased by the variable resistance.

$$P_s = T \omega \quad (2)$$

$$\eta = \frac{P_s}{P_h} \quad (3)$$

where P_s means Shaft power [W], T means Torque by axis [Nm], ω means Angular velocity of turbine [rad/s] and η means Turbine efficiency.

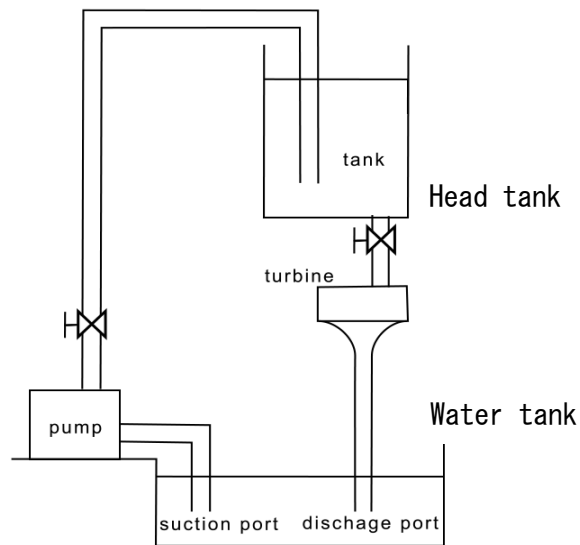


Figure 4. Experimental setup.

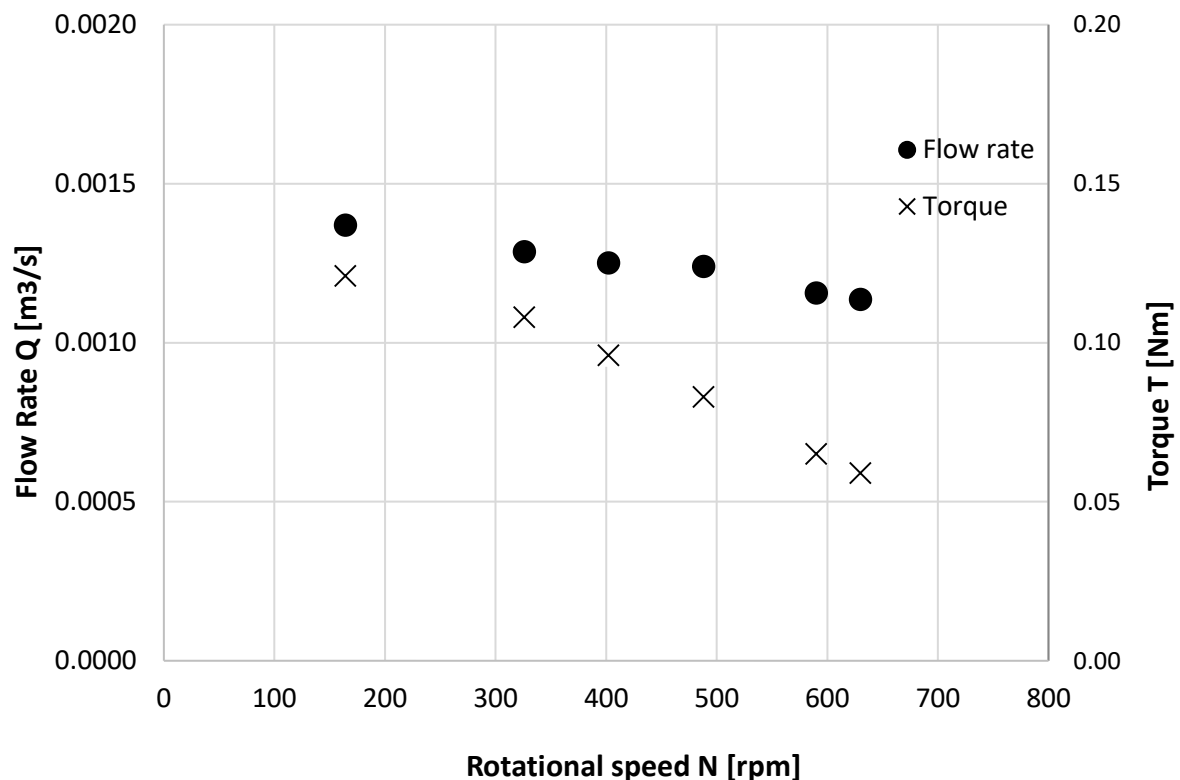


Figure 5. Measured values of flow rate and torque.

4. Results and discussion

The flow rate range measured at the inlet part was from $0.0011 \text{ m}^3/\text{s}$ to $0.0014 \text{ m}^3/\text{s}$. The data of rotational speed N and rotation torque T were measured by the experiment. These measured values were shown in figure 5. The shaft powers, which were produced by turbine, were calculated by measured values of each point. The calculated power output characteristics are shown in figure 6. Maximum outputs were recognized in the case of around about 500 rpm. Highest output of our

experiment were 4.24 W. This result was greatly less than the targeted value. An efficiency of this system could be calculated as the ratio of shaft power to water power (equation (3)). The calculated efficiency is shown in figure 6, too. If improvement of the efficiency is planned, the output may greatly exceed it from the targeted value.

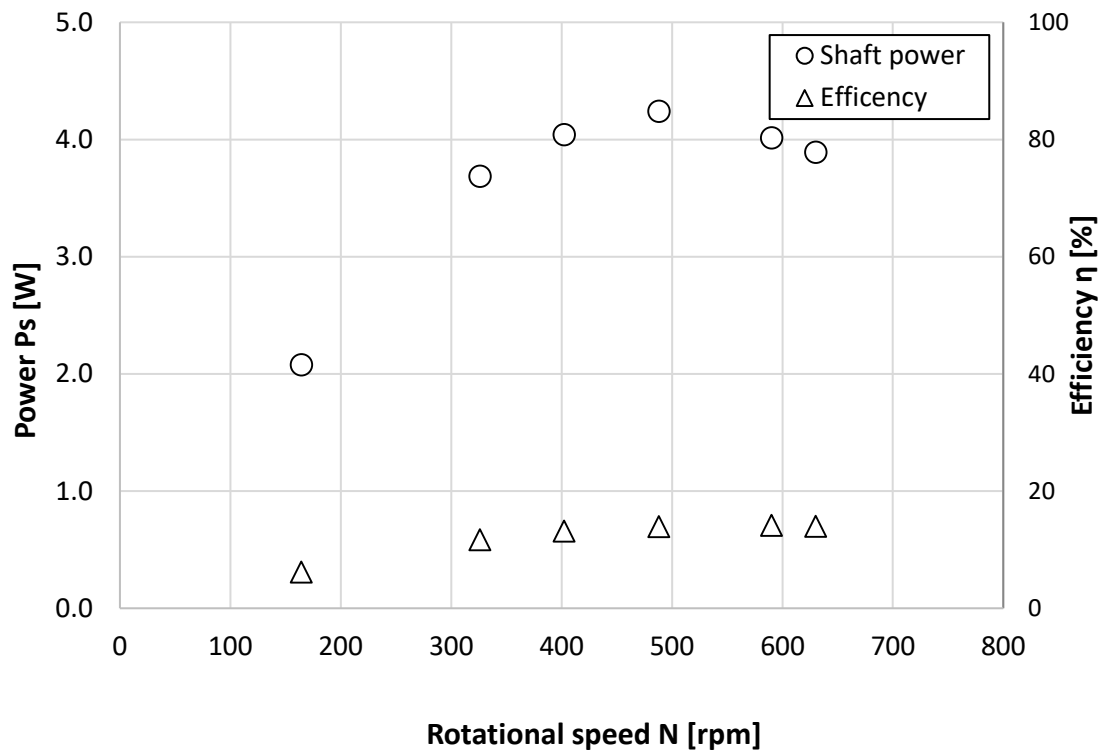


Figure 6. Distribution of shaft power and efficiency.

We calculated the specific speeds from my experimental data by following equation (4). P_s in the equation indicates the shaft power. The power was given by the product of measured torque and rotational speed.

The clearance between the casing wall surface and the turbine tip is very narrow. Therefore, it can be expected that the fluid flows between the turbine blades, but it was difficult to visually check the fluid. We were able to observe the swirling flow in the discharge section.

$$N_s = N \frac{\sqrt{P_s}}{H^{\frac{5}{4}}} \quad (4)$$

where N_s means Specific speed (m-kW) and N means Rotational speed [rpm].

In table 2, the specific speed of Quasi-Peace model and the other type is recorded.

Table 2. Specific speed.

Water Turbine		Specific Speed
Impulse Turbine	Pelton	8 ~ 25
Reaction Turbine	Francis	50 ~ 300
	Kaplan	200 ~ 900
	Tubular	500 >
	Quasi-Peace (our model)	2~12

5. Conclusions

We designed a new type turbine for micro hydro power generation. We could get the basic performance of the turbine, which was fabricated by the 3D printer, in scale downed model experiment.

The following conclusions can be drawn:

- In the measurement of shaft power characteristics, the maximum power is $P_s=4.24$ W.
- Calculated specific speed of our model turbine is 2 – 12.

We continue our study on the new type turbine for optimum performance with taking into consideration the blade shape and casing shape.

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