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Proposal and Fundamental Experiments on Duct-shaped Water Wheel without Rotating Blades

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ABSTRACT

In the present paper, a new type duct-shaped water wheel is proposed and its performance is evaluated by fundamental experiments. Trial models based on the proposed basic ideas and their revised models are tested. As an example, maximum efficiency is improved from 1.9 % to 7.7 % by revised designs of shapes based on the experiments. For this new type duct-shaped water wheel, more practical improvements are expected in the future works.

Keywords

Unconventional water wheel, Duct-shaped water wheel, Rotating blade, Circulating water channel.

1 INTRODUCTION

One of the authors proposed a new ducted propulsor without rotating blades (Suzuki 2013). A conventional screw propeller has large rotating blades to get effective thrust force, and the respective blades advance in water like screws. As shown in Figure 1, however, the proposed new propulsor has a duct, a rotating boss and vanes with screw surfaces arranged and fixed on the duct inner surface. Viscous rotational flows caused by rotating motion of boss are curved by the vanes along the duct inner surface. According to this inner flow, suction flows at the front side and accelerated blowing flows at the rear side can be induced.

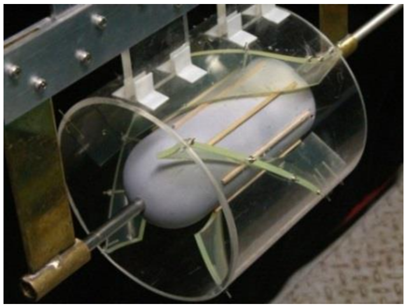

Figure 1: Test model of new ducted propulsor without rotating blades (Suzuki 2013).

If introducing the idea of this new propulsor, a new duct-shaped water wheel (current turbine) can be proposed in consideration of the relationship between a conventional screw propeller and a conventional windmill.

An example of the model of proposed new water wheel is shown in Figure 2. An incident uniform flow into the duct is curved spirally along the vanes with screw surfaces. This spiral flow can induce a rotational motion of the boss with protuberances. From this rotational motion, energy for generation of electricity can be obtained. In the present study, fundamental experiments on various test models of the proposed new water wheel are carried out in a circulating water channel which has 600 mm depth in Yokohama National University. According to the experimental results, effects of basic parameters related to this new water wheel and the efficiencies are investigated.

Figure 2: Proposed new duct-shaped water wheel without rotating blades.

2 TESTED MODELS AND EXPERIMENTS ON THEIR ROTATIONAL PERFORMANCES

2.1 Trial Models

Specifications of duct-shaped water wheel model are shown in Table 1. Trial experiments are carried out by using the models with 4, 6 or 8 vanes and boss types A, B or C in Figure 3. Experimental cases are defined in Table 2. In all cases, a submergence depth at model center line is fixed as 300 mm in the circulating water channel with the depth of 600 mm in Yokohama National University.

Table 1: Specifications of duct-shaped water wheel model

Parts	Materials	Specifications
Duct	Acrylic pipe	Length 330 mm Outer radius 300 mm Inner radius 290 mm
Cap	SUS	Radius 130 mm
Vane	SUS	Thickness 3 mm
Boss	Chemical wood	Length 200 mm Radius 130 mm Height of protuberance 10 mm

Table 2: Experimental cases for trial models

Number of vanes	Boss type	Case No.
4	A	Case 4-A
	B	Case 4-B
	C	Case 4-C
6	A	Case 6-A
	B	Case 6-B
	C	Case 6-C
8	A	Case 8-A
	B	Case 8-B
	C	Case 8-C

(Depth of submergence 300mm)

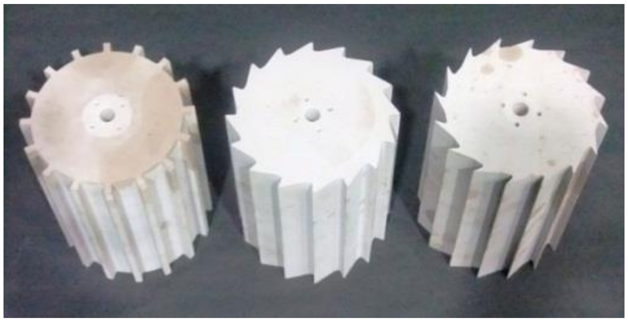

Figure 3: Boss types: A, B and C

As the first step, their rotational performances are tested to measure the number of rotations in respective cases under no load condition (free rotational motion). The experimental results are discussed in section 2.3 with the results for the following revised models.

2.2 Revised models

As shown and discussed in the next section 2.3, rotational performances of the trial models are not so effective. In order to improve the trial models, the boss type D with spiral protuberances that the spiral angle is 45 deg. shown in Figure 4 is tested to compare with the experimental results of the boss type C. In those cases, the number of vanes is decreased less than the trial cases as 2, 3 or 4. Experimental cases are defined in Table 3.

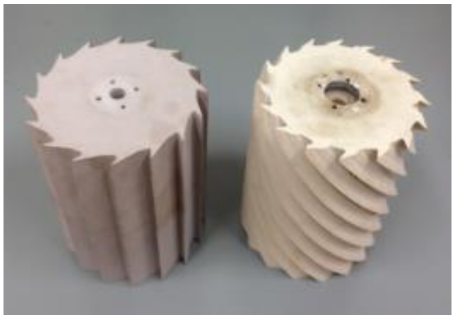

Figure 4: Boss types: C and D

Table 3: Experimental cases for revised models

Number of vanes	Boss type	Case No.
2	C	Case 2-C
	D	Case 2-D
3	C	Case 3-C
	D	Case 3-D
4	C	Case 4-C
	D	Case 4-D

(Depth of submergence 300mm)

Table 4: Experimental cases for submergence effects

Depth of submergence	Supposed environments	Case No.
75 mm	Shoal	Case 4-D 75 mm
150 mm	Near free surface	Case 4-D 150 mm
300 mm		Case 4-D 300 mm
450 mm	Near bottom	Case 4-D 450 mm

In addition to the experimental cases for the trial and revised models, submergence effects for the boss type D are investigated as shown in Table 4 under respective supposed environments.

2.3 Experimental results of rotational performances

In order to investigate the rotational performances for the cases in Tables 2, 3 and 4, the number of rotations in respective cases is measured under no load condition in the circulating water channel. Typical results are shown in Figures 5, 6 and 7.

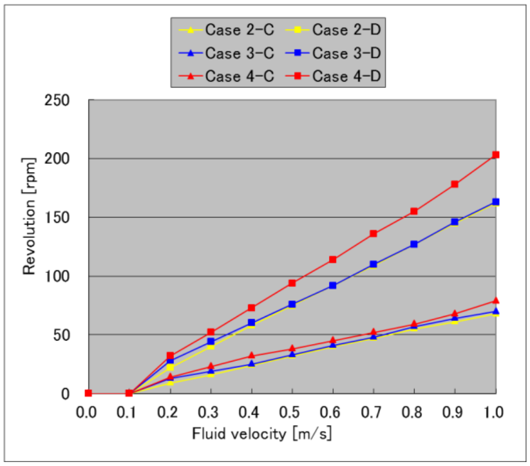

Figure 5: Number of rotations (Case 2-C~Case 4-D 300 mm)

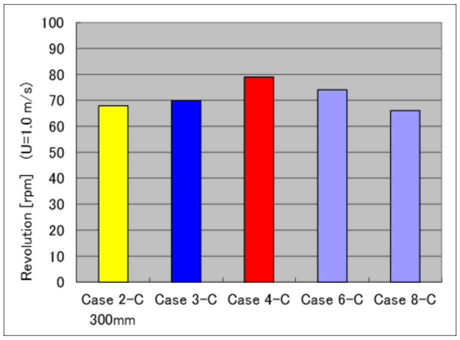

Figure 6: Number of rotations (2, 3, 4, 6 and 8 vanes, *U*=1.0 m/s)

In Figure 5, the rotational performances are compared among the cases in Table 3 for boss types C and D. The other cases defined in Table 2 for trial models show worse performance than those shown in Figure 5. The effects of number of vanes are tested as shown in Figure 6 using the boss type C. According to the results in Figure 6, the optimum number of vanes may be 4; however, 5 vanes should be tested. The submergence effects are also investigated as shown in Figure 7 for the cases in Table 4. The best supposed environment is the case for near free surface; however, except the case for near bottom, remarkable differences are not appeared.

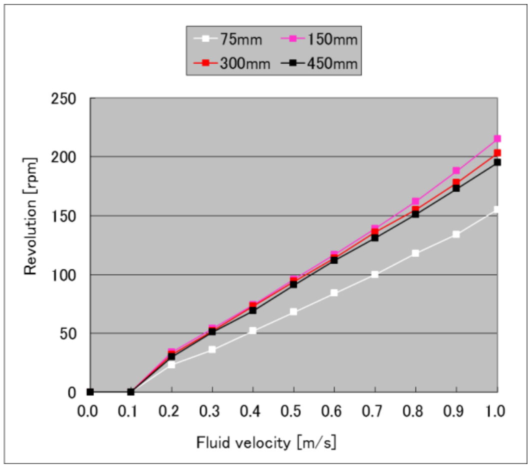

Figure 7: Number of rotations (Case4-D 75,150,300,450 mm)

3 EXPERIMENTS ON GENERATION OF ELECTRICITY

3.1 Experimental procedures

An electric generator illustrated in Figure 8 is installed in the cap of duct-shaped water wheel model. This generator has 12 poles and the magnet can rotate to generate electricity. By using this generator, three-phase alternating current can be obtained.

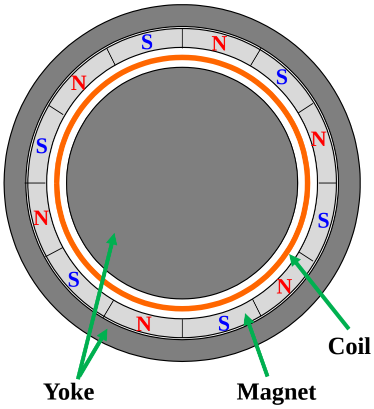

Figure 8: Generator arrangement

The efficiency of generator can be evaluated by the procedures shown in Figure 9. Before the experiments on generation of electricity in the circulating water channel, the calibration tests of torque are carried out to get the calibration curves (lines) between the number of rotations and the torque.

In the experiments of generator, the internal resistance is controlled by the variable circuit to change the number of rotations. From the experiment, the mono-phase alternating current like Figure 10 can be measured. As the present generator has 12 poles, the number of rotations n is calculated by equation (1),

$$n = \frac{1}{6T} \tag{1}$$

where T is a period of mono-phase alternating current. The torque Q of generator is evaluated from the number of rotations n by using the calibration line based on the calibration test of torque. The output of generator P, the uniform flow energy into the duct P_0 and the efficiency of generator η are evaluated by equations (2), (3) and (4) respectively,

$$P = 2\pi nQ \tag{2}$$

$$P_0 = \frac{1}{2}\rho AU^3 \tag{3}$$

$$\eta = \frac{P}{P_0} \tag{4}$$

where ρ is the fluid density, A is the inflow sectional area of duct and U is the uniform flow velocity in the circulating water channel.

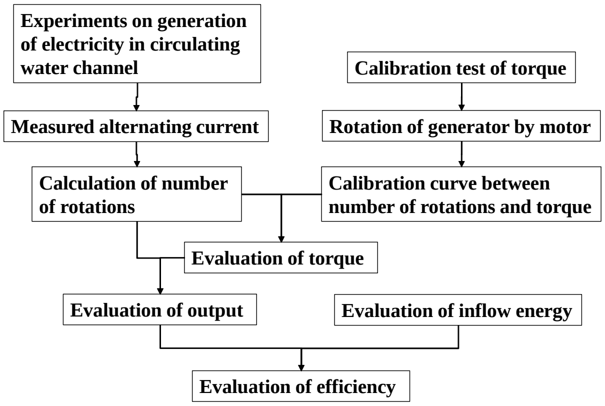

Figure 9: Flow diagram of experiments

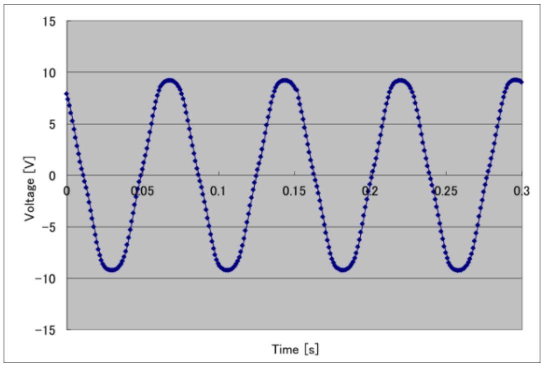

Figure 10: An example of obtained mono-phase alternating current.

3.2 Results of generation of electricity

In every experiment of trial cases, generations of electricity have been succeeded. The best one is Case 4-C with 4 vanes and the boss type C; however, its maximum efficiency is 1.9 %. Through all cases in the present study, the best performance is obtained in Case 4-D 150 mm with 4 vanes and the boss type D at the depth of submergence 150 mm shown in Table 4.

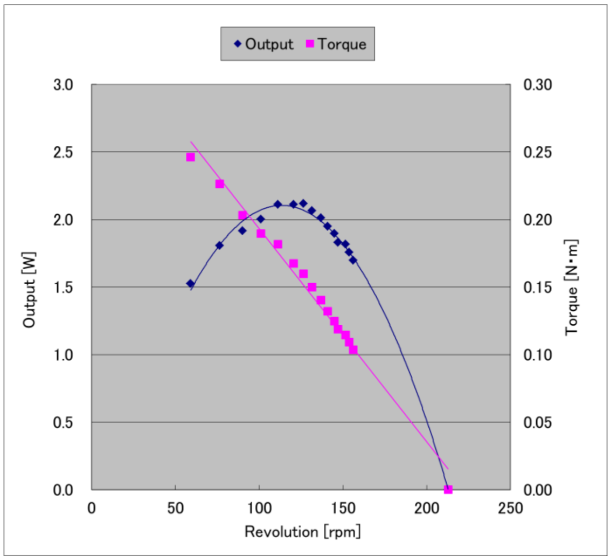

Figure 11: Output and torque (Case 4-D 150 mm U=1.0 m/s)

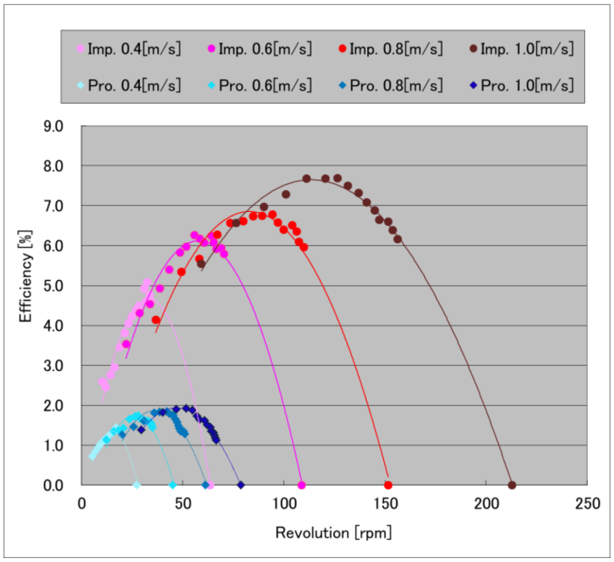

Figure 12: Generator efficiency (Pro.: Case 4-C 300 mm and Imp.: Case 4-D 150 mm)

An example of measured results of the output of electricity and the torque are shown in Figure 11. Through the improved cases in Table 3 and the cases to investigate submergence effects in Table 4, maximum efficiency is improved from 1.9 % (in Case 4-C 300 mm) to 7.7 % (in Case 4-D 150 mm) as shown in Figure 12. In order to improve the efficiency as future works, more detailed parametric studies on the specifications listed in Table 1 and studies on the shape optimizations of boss and duct should be carried out.

5 CONCLUDING REMARKS AND FUTURE WORK

In the present study, the authors propose a new duct-shaped water wheel without rotating blades. This water wheel has vanes with screw surfaces arranged on the duct inner surface and the rotating boss with protuberances. An incident uniform flow into the duct is curved spirally along the vanes, and the spiral flow induces a rotational motion of the boss to generate electricity. In this paper, experimental investigations on the rotational performances under no load condition and on the generation of electricity are carried out.

The proposed duct-shaped water wheel is very compact and it can be expected stronger than the conventional screw propeller type wheel; however, as the future works, the efficiency should be improved. The maximum efficiency based on the present experiments is 7.7 %. For the practical use as the generator, the maximum efficiency should be improved upon about 30 %. Since the various parameters are related to the proposed new water wheel, the improvements can be expected as the future works by more detailed experiments and/or CFD simulations.

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