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Open Water Tests of Unconventional Ducted Propulsor without Rotating Blades in Circulating Water Channel

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ABSTRACT

A conventional screw propeller has large rotating blades to get effective thrust force, and the respective blades advance in water as screws. In the present study, an unconventional ducted propulsor is proposed. It has a duct, a rotating boss and vanes with screw surfaces installed 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.

In the present paper, open water tests on performances of this new propulsor are carried out and reported. Trial models and their revised models based on the various design parameters are investigated. As results of the experiments in a circulating water channel, thrust forces caused by the new propulsor are confirmed, however, propeller efficiencies are lower than those of conventional screw propeller. For this new type duct-shaped propulsor, more practical improvements should be expected in the future works.

Keywords

Thrust force, duct, rotating blade, boss, open water test

1 INTRODUCTION

In the previous symposium "smp'13", the authors proposed an unconventional ducted propulsor without rotating blades (Suzuki, 2013). It has a duct, a rotating boss and vanes with screw surfaces installed on the duct inner surface. Viscous rotational flows caused by rotating motion of boss with some protuberances are curved by the vanes along the duct inner surface. According to this inner flow, accelerated flows at the rear side of duct can be induced to get thrust forces.

In the studies presented in "smp'13", two types of fundamental experiments are carried out. One is flow visualization in a wind tunnel by using smoke for a simple model based on the new concepts proposed by the authors. In the second fundamental experiments, for more complicated propulsor models having various sets of parameters, model experiments are carried out in a circulating water channel. In those experiments, accelerated flow velocity distributions behind the model are measured to get momentum increments. Basic information and knowledge are obtained from those fundamental experiments.

As the related works, in the symposium "smp'15", the authors proposed a duct-shaped water wheel without rotating blades for the purpose of generation of electricity, which is based on the consideration about relationship between a conventional screw propeller and a conventional windmill. In every experiment of trial cases and improved cases carried out in the circulating water channel, generations of electricity are succeeded (Suzuki, 2015).

In the present new studies for "smp'17" symposium, open water tests of the new propulsor proposed in "smp'13" are carried out. Trial models and their revised models with different design parameters are tested in the circulating water channel. As results of the present experiments, it is confirmed that thrust forces can be obtained by the new propulsor in every case; however, propeller efficiencies are lower than those of conventional screw propeller. Detailed results for the proposed models with some different design parameters are shown and discussed in the present paper.

2 EXPERIMENTAL METHODS AND ANALYSIS

In the present study, open water tests of the proposed unconventional propulsor are carried out in the circulating water channel. In order to analyze performances of the new propulsor, similar hydrodynamic coefficients as the open water characteristics for conventional screw propellers are used.

2.1 Open Water Tests in Circulating Water Channel

The circulating water channel in YNU is used for the open water tests, which has the following specifications.

Type: Vertical circulation type with 2 impellers
Maximum flow velocity: 1.0 m/s
Experimental section: 2.50 m length, 1.20 m breadth and 0.60 m depth

Examples of experimental setup of the open water test for models based on the new propulsor concept are shown in Figure 1 and 2. As shown in these photos, the new propulsor has a duct with some curved vanes (red ones) and a rotating boss with some protuberances (white ones).

The boss is connected to a motor through a shaft, a bevel gear (gear ratio 2:1) and a vertical axis (red one).

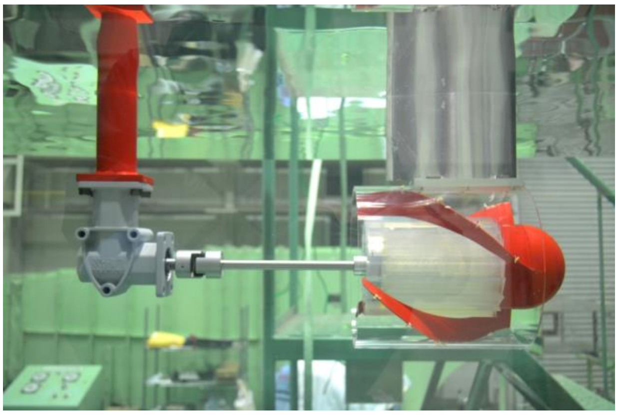

Figure 1: Experimental setup of open water test for a trial model (upstream: right)

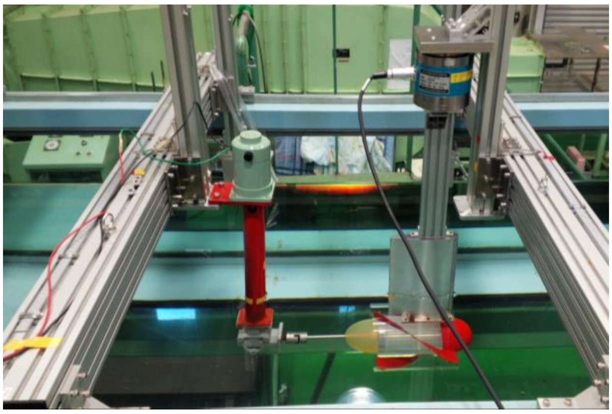

Figure 2: Experimental setup of open water test for a revised model (upstream: right)

2.2 Open Water Characteristics

Hydrodynamic forces like drag and thrust acting on the duct can be measured directly by a load cell connected by a fixed strut. However, the torque of boss is evaluated by using a calibration curve based on relations between torques and input electric currents. The calibration data should be prepared before the open water tests. The hydrodynamic characteristics of the new propulsor based on the open water tests are analyzed by the following coefficients defined as similar as the conventional ones.

Advance ratio: $$J_T = \frac{U}{nD} \quad (1)$$

Thrust coefficient: $$K_T = \frac{T}{\rho n^2 D^4} \quad (2)$$

Torque coefficient: $$K_Q = \frac{Q}{\rho n^2 D^5} \quad (3)$$

Propeller efficiency: $$\eta_0 = \frac{J_T K_T}{2\pi K_Q} \quad (4)$$

In these coefficients, U is the uniform flow, T is the thrust, Q is the torque, n is the number of revolutions of boss, D is the diameter of boss and ρ is the fluid density.

3 RESULTS OF OPEN WATER TESTS

Open water tests are carried out for trial models based on the information obtained from the previous study in "smp'13" (Suzuki, 2013). According to the experimental results for the trial cases, revised models are planned. In this chapter, specifications of models and experimental results are shown and discussed.

3.1 Trial Models and their Characteristics

Specifications of trial models are shown in Table 1 and the experimental cases are defined as shown in Table 2. The outline of trial model is given in Figure 1 and the detailed shapes of boss with protuberances are shown in Figure 3. As shown in Table 1, the radius ratio κ of boss (62 mm) to duct (95 mm) is selected as $\kappa \approx 0.65$, according to the theoretical consideration in the previous study for "smp'13" (Suzuki, 2013).

Table 1: Specifications of trial models

Parts	Materials	Specifications
Duct	Acrylic pipe	Length: 205 mm, Inner radius: 95 mm, Outer radius: 100 mm
Cap	Chemical wood	Semi sphere, Radius: 52 mm
Vane	SS41	Thickness: 1 mm, Height: 31.5 mm, Screw surface, Vane angle on duct inner surface: π/4 rad.
Boss	ABS (by 3D printer, in Figure 3)	Length: 160 mm, Radius: 62 mm,
		Number of protuberances: 16, Height of protuberance: 10 mm, Type A: straight protuberances, Type B: spiral protuberances with angle π/4 rad. on boss
Shaft	SUS	Diameter: 12 mm
Strut of duct	HFS5-2060 Aluminum	Length: 160 mm, Thickness: 34 mm, Section: NACA65(4)-202

Table 2: Experimental cases for trial models

Cases	Duct	No. of vanes	Boss	Fairing
Case 1	without taper	3	A	without rear fairing
Case 2			B	
Case 3		4	A	
Case 4			B	
Case 5		5	A	
Case 6			B	

Open water tests are carried out by the experimental procedures discussed in the previous chapter. Thrust forces can be obtained in every case in Table 2. Among these cases, the best one is Case 1 with 3 vanes and boss type A. The spiral protuberance is effective for the duct-shaped water wheel without rotating blades discussed in "smp'15", but it is not effective as to the propulsor. The open water characteristics of Case 1 are shown in Figure 4. As shown in Figure 4, the tendency of open water characteristics of new propulsor is different from those of conventional screw propeller. The propeller efficiencies are much lower than the conventional ones, because all trial models have no faring to induce the dead water zone causing drag and lower efficiency.

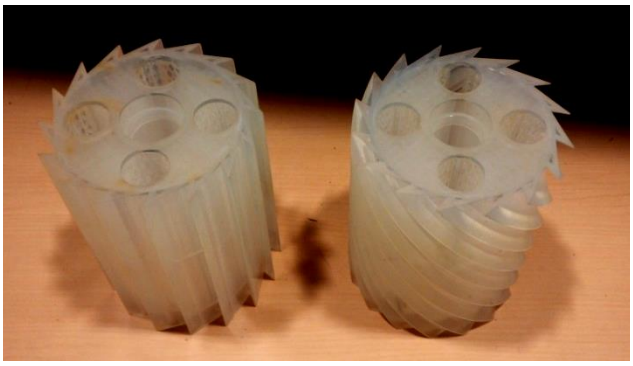

Figure 3: Boss types: A (left) & B (right)

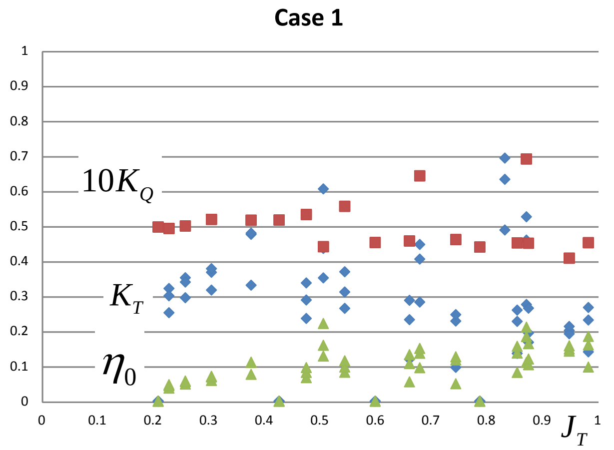

Figure 4: Open water characteristics of Case 1

3.2 Revised Models and their Characteristics

Revised models are planned based on the experimental results for trial models. Specifications of revised parts are shown in Table 3 and the experimental cases are defined as shown in Table 4. The outline of trial model with rear fairing part can be found in Figure 2 and more detailed photo is shown in Figure 5. The dead water zone can be reduced effectively by this fairing. The tapered duct model is shown in Figure 6.

Table 3: Specifications of revised parts

Parts	Materials	Specifications
Rear fairing	ABS (by 3D printer, in Figure 5)	Length: 81 mm, Outer radius connected to boss: 62 mm
Tapered duct with vanes	ABS (by 3D printer, in Figure 6)	Length: 200 mm, Front outer radius: 125 mm, Rear outer radius: 100 mm, Thickness: 5 mm, Vane angle: $\pi/4$ rad.

Table 4: Experimental cases for revised models

Cases	Duct	No. of vanes	Boss	Fairing
Case 7	without taper	3	A	with rear fairing
Case 8			B	
Case 9		4	A	
Case 10			B	
Case 11		5	A	
Case 12			B	
Case 13	with taper	3	A	
Case 14			B	

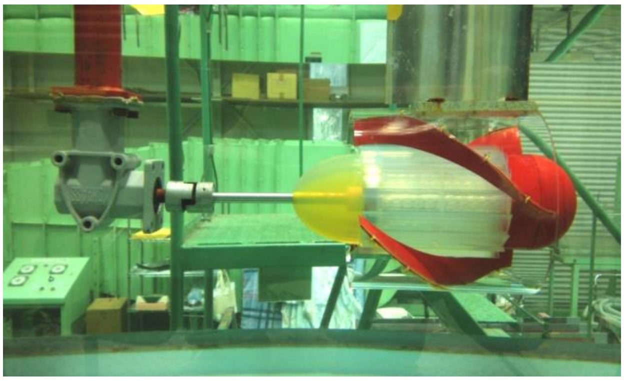

Figure 5: Boss with rear fairing

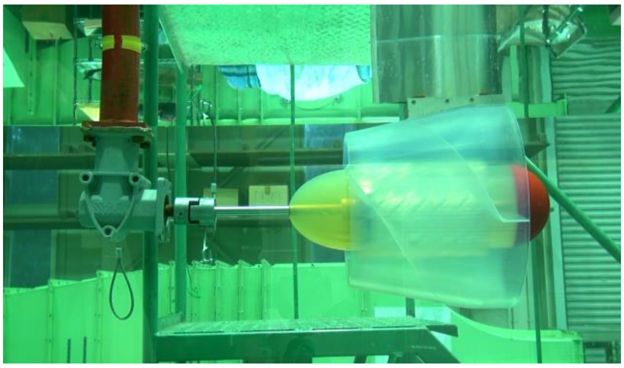

Figure 6: Tapered duct

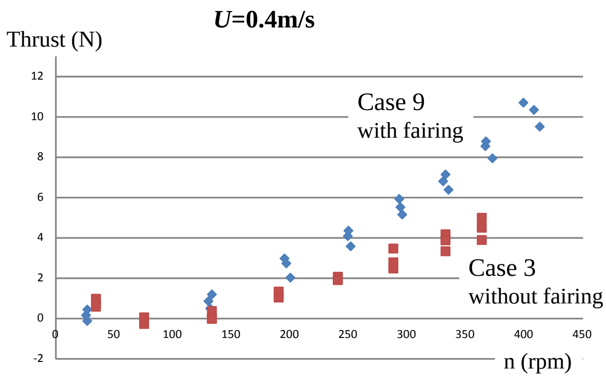

Figure 7: Effect of rear fairing

As shown in Table 4, open water tests are carried out for 8 revised cases and thrust forces can also be obtained in every case. Summarized experimental results can be described as follows.

(1) As trial cases, the spiral protuberance is less effective than the straight protuberance.
(2) The effect of rear fairing is small for the models with 3 vanes; however, it is very effective for those with 4 or 5 vanes.
(3) The tapered duct is not effective except the conditions of high advance ratio in the present cases with 3 vanes.

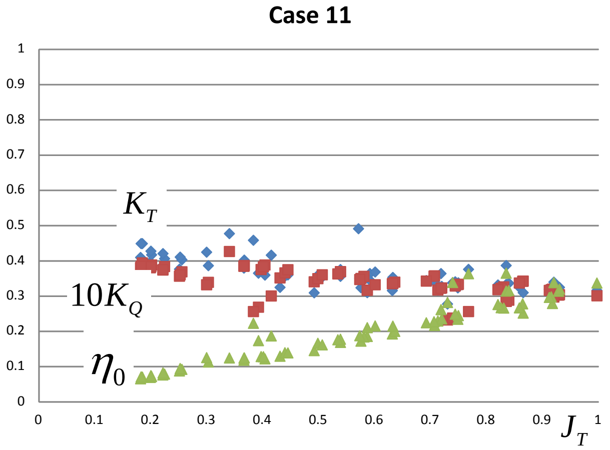

Figure 8: Open water characteristics of Case 11

Examples of the effect of rear fairing are shown in Figure 7. Obtained thrust forces are remarkably increased. Among the experimental cases shown in Table 4, the best one is Case 11 with 5 vanes, boss type A, rear fairing, and no taper. The open water characteristics of Case 11 are shown in Figure 8. The propeller efficiency can be improved and it becomes larger than 0.3 in high advance ratios, however it is also lower than those of conventional screw propeller. Since the experimental cases and conditions are limited in the present studies, extended investigations on various design parameters and numerical or experimental studies on the shape optimizations of boss and duct should be expected as the future works.

4 CONCLUDING REMARKS

As results of the present experimental studies, it is confirmed that thrust forces can be obtained by the new propulsor in every case using trial models and their revised models; however, propeller efficiencies are lower than those of conventional screw propeller. In the present studies, however, experimental cases and conditions are limited. As many design parameters are related to this new type duct-shaped propulsor, more practical improvements will be expected as the future works. Various parametric studies and the shape optimizations of boss and duct should be expected.

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