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Development of ocean current marine turbine

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Abstract. Owing to huge amount of kinematic energy, ocean current has the potential to be a base power source, it's also source for huge and steady flow energy. Moreover, Japan has potential ocean area -which can be used for large scale power production. One example is Kuroshio which is one of the strongest ocean current. However, since the flow velocity of a steady ocean current is low compared with the velocity of the tidal current, development of a system which can efficiently generate power in the low flow velocity is needed. Prototype testing is complicated because the area where Kuroshio current located is far from on shore. In this study, development of blades, water bearing, and a drive train suitable for a generation of electrical energy at the low flow velocity and towing test was carried out.

1. Introduction

Recently ocean renewable energy has captured global attention. Many offshore turbines have, since their first installation in Denmark in 1991[1], been installed all over the world. Other offshore energy resources are now consideration for power generating systems utilizing wave, tidal and ocean current power, frequently referred to as marine hydrokinetic energy[2]. Wave power is highly variable resource and many type of wave energy generator are under development. Tidal and ocean current power generation systems utilize turbines similar to that of wind turbine.

Table 1 shows comparison of characteristics among offshore renewable energy convertors such as wind turbine, wave generation, tidal and ocean current power generation. Wind power, which is a very widespread renewable energy source, and wave power, which has large amount of potential energy, depend on atmospheric and sea conditions and therefore are subject to highly irregular fluctuations in the amount of energy. Thus, they are unstable sources of power with a lower capacity factor. The target point of tidal current power generation is straits between islands where the current speed is high. The daily amount of energy is constant, although fishery rights and the interests of other industries and stakeholders, who utilize these water resources, have to be considered in defining the sea area for installation. In locations where there is a well-defined and stable ocean current, ocean current energy



is advantageous because it can be baseload power. However, since the flow velocity of a steady ocean current is low compared with the velocity of the tidal current, there is a need to develop a system which can efficiently generate power in the low flow velocity. And it is difficult to test using prototype because the area where Kuroshio current located is far from on shore.

In this study, development of important components ocean current power generator such as blades, water bearing, and a drive train suitable for a generation of electrical energy at the low flow velocity, and towing test in the sea was carried out.

Table 1. Characteristics of ocean renewable energy.

	Off-shore Wind Turbines	Wave-Activated Power Generation	Tidal Current Power Generation	Ocean Current Power Generation
Characteristics of Energy	Not constant since wind is subject to weather conditions. Many places on land and at sea to install turbines.	Not constant since waves are subject to weather conditions. Huge widespread installation potential.	Variable daily but constant energy output. Changeable current directions will limit the utilization and capacity factor.	Ocean currents are regular and constant resulting in high predictability and high capacity factor. Over the long term currents may shift.
Capacity Factor Range	35-50%[3]	25-35%[3]	26%-50%[3]	60-70%
Ideal Location	Offshore waters with steady winds and shallow seabed for installations.	Coastal areas with strong offshore winds.	Near the coast of a strait, between islands, etc.	Tens of kms offshore in major and minor currents.
Deployment Examples	On seabed: Many achieved (ex. Horns Rev, Denmark). Floating (trials in Norway and Japan)	Prototyping stage: ex. Columbia Power Technologies	Many examples, like Marine Current Turbines (UK) started its commercial unit operation in December, 2008	None deployed; under development.
Technical problems	-Designed for shallow water -High cost of base structure in deep water.	-Large variety of converters -High-efficiency type still not found.	-Siting constraints, such as fisheries. -Maintenance method in strong current needs to be examined.	-Great cable laying cost for long offshore distance -Difficult maintenance for submerged structure

2. Design of Towing Test Model

2.1. Design concept of towing test model

Prototype Concept design and basic configuration of ocean current turbine is illustrated in Figure 1. Main components are mooring ropes to keep the position of ocean current turbine in design depth in the rated current speed, blades and rotors to convert flow power of ocean current to mechanical

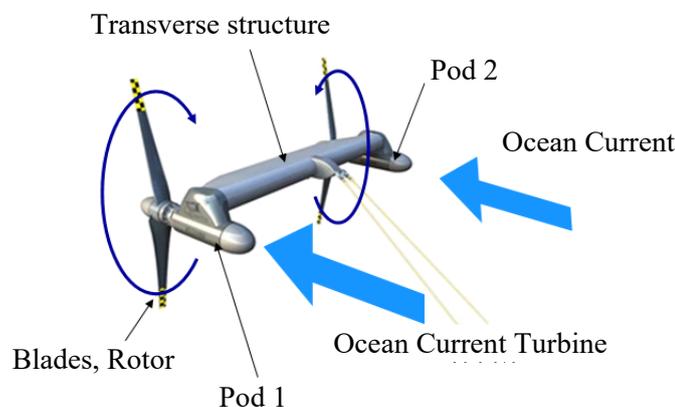


Figure 1. Prototype concept design and basic configuration of ocean current turbine.

rotational power and pods to generate electric power from rotational power. Two pods are connected by transverse structure, which is a strength member. Main bearing is shown in next section.

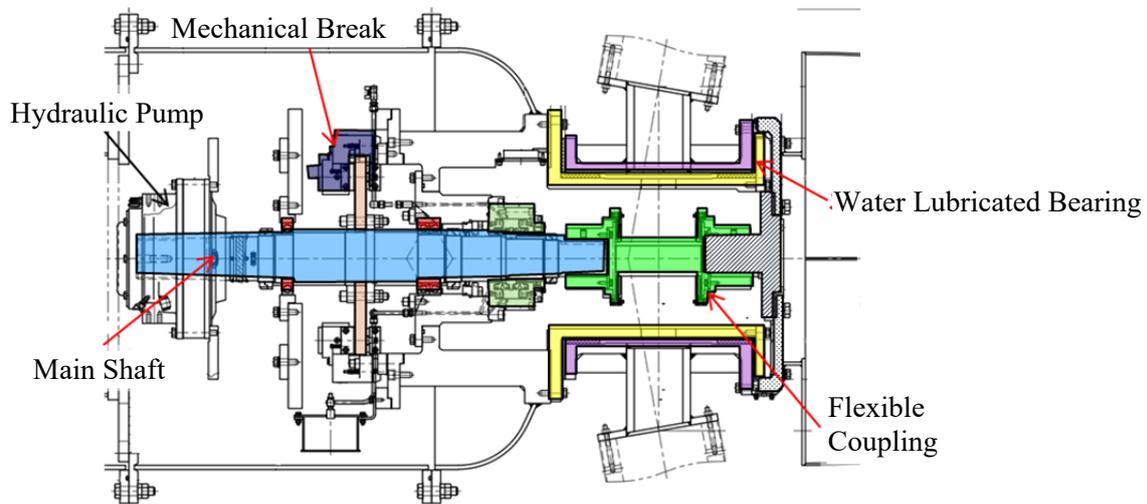


Figure 2. Components of drivetrain.

2.2. Design of water lubricated bearing

Figure 2 shows components of drivetrain of test model in this study. Torque and thrust forces due to rotation are supported by water lubricated bearing in the journal and thrust direction. This constitution realizes transmission of only rotational torque to a main shaft which is connected to a hydraulic pump through the pod. Furthermore, this transmission is consisted of flexible coupling, which can realize small diameter of main shaft and decrease load to the bearing. Small fluctuation of the main shaft load contributes to the reliability of watertight characteristics of bearing seal.

2.3. Test model

Test model made in this study and its specification is shown in Figure 3. Rotor Diameter is 4.7m, and total weight in air is about 25ton. Because it is difficult to keep buoyancy by only two pods, another buoyancy body is installed out of rotor phase. This model is expected to generate about 20kW in the 1.5m/s current.

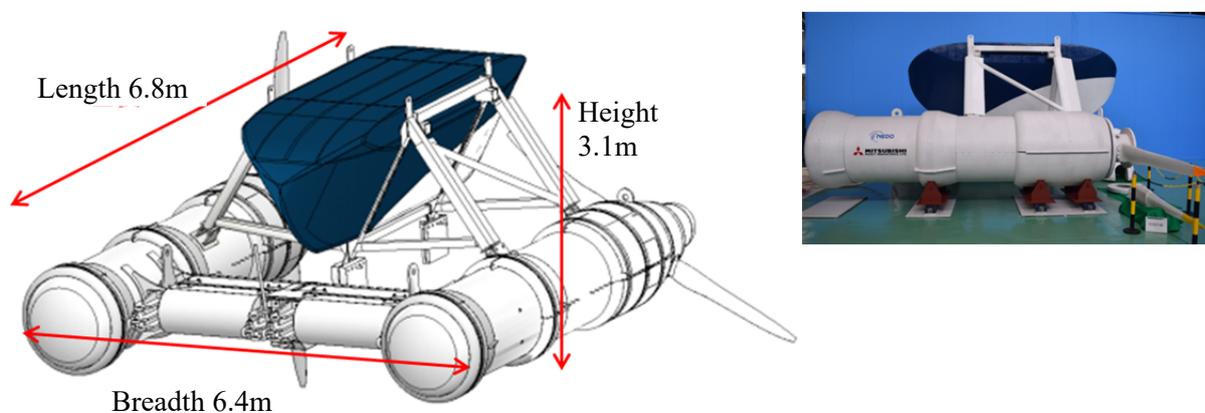


Figure 3. Test model of ocean current turbine.

3. Towing test

3.1. Test area and procedure

Figure 4 shows test sea area of Iojima Island where the towing tests were carried out from 26th to 28th August 2016.

Towing test method is shown in Figure 5. Tug boat is connected to barge by Towing rope for towing. 5m support rod was attached to the edge of the barge and hawser was attached to the end of the rod. In this test, towing speed is set to target current speed and tests for start-up characteristics and power curve were carried out.

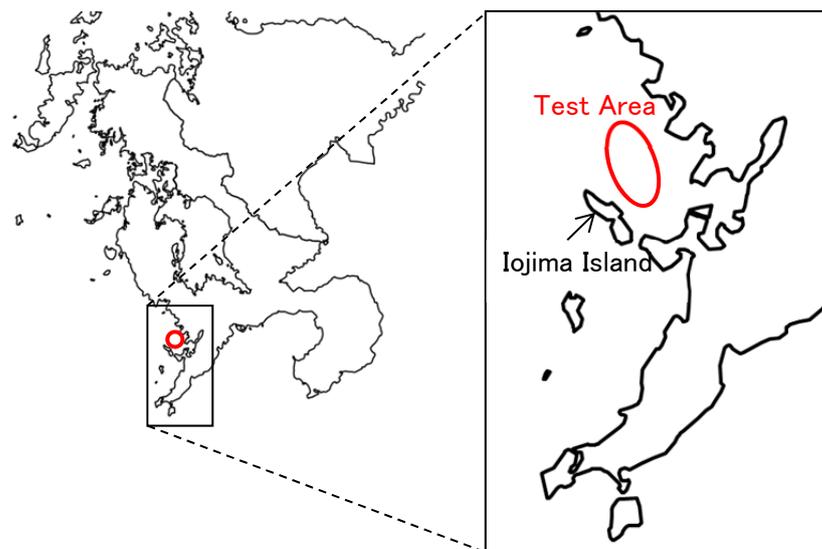


Figure 4. Test sea area.

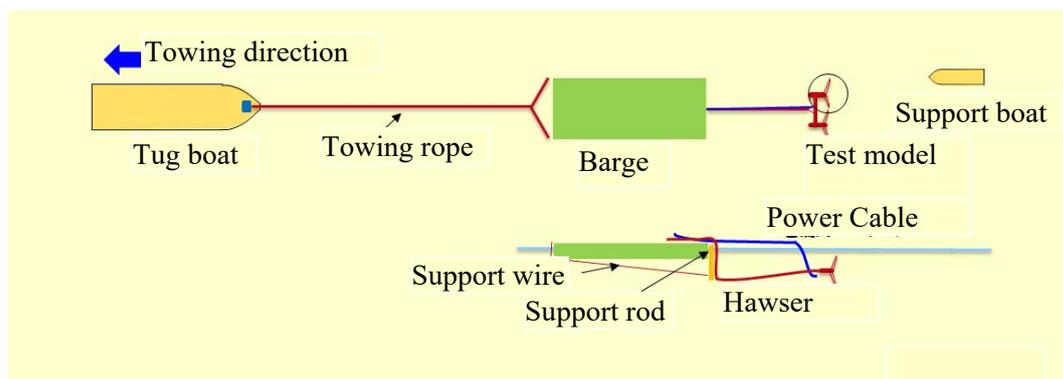


Figure 5. Towing method.

3.2. Verification items

Tests items are shown in Table 2. Tests for start-up characteristics and power curve were carried out.

Table 2. Test items.

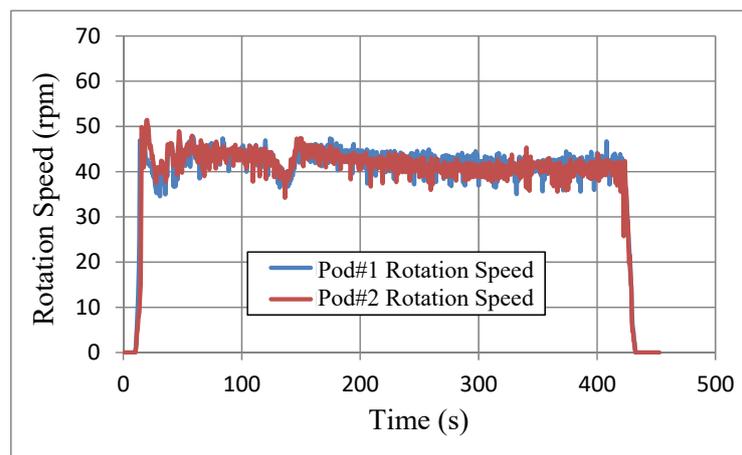
No	Items	Towing Speed
1	Start-up Characteristics	
2	Power Curve	0.7~1.8 m/s

3.3. Results of towing tests

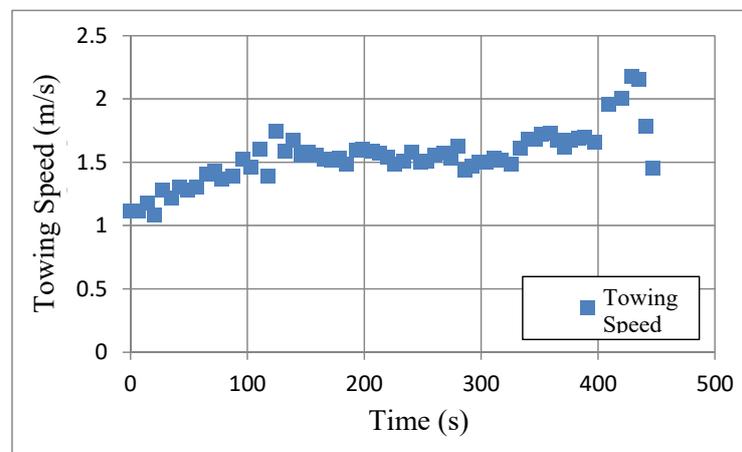
3.3.1. Start-up characteristic conditions

To keep posture and position, rotors must begin to rotate simultaneously with towing to keep thrust forces acting uniform to each rotor. The test model is also equipped with hydraulic motors to assist the start of rotation (9rpm).

Figure 6 shows results of start-up test. Rotation speed increased smoothly to rated rotation speed (42.7rpm) and stable motion of test model during towing was confirmed.



Rotation speed



Towing speed

Figure 6. Start-up characteristics test results (1.5m/s).

3.3.2. Power curve of the equipment

Towing tests at several towing speed (0.7~1.8m/s) were carried out and amount of power generation was verified. Test results (Rotation speed, Pitch Motion) in high current speed (1.5m/s) are shown in Figure 7 and power curve is shown in Figure 8. Calculation line of output at rotor in Figure 8 is calculated using the following formula.

$$\text{Output at Rotor} = \frac{1}{2} C_p \rho A V^3$$

C_p : Power Coefficient

ρ : Density of sea water

A : Rotor Area

V : Current Speed

Power output results at rotor for each towing speed are almost consistent with theoretical output and the validity of components around drivetrain is confirmed.

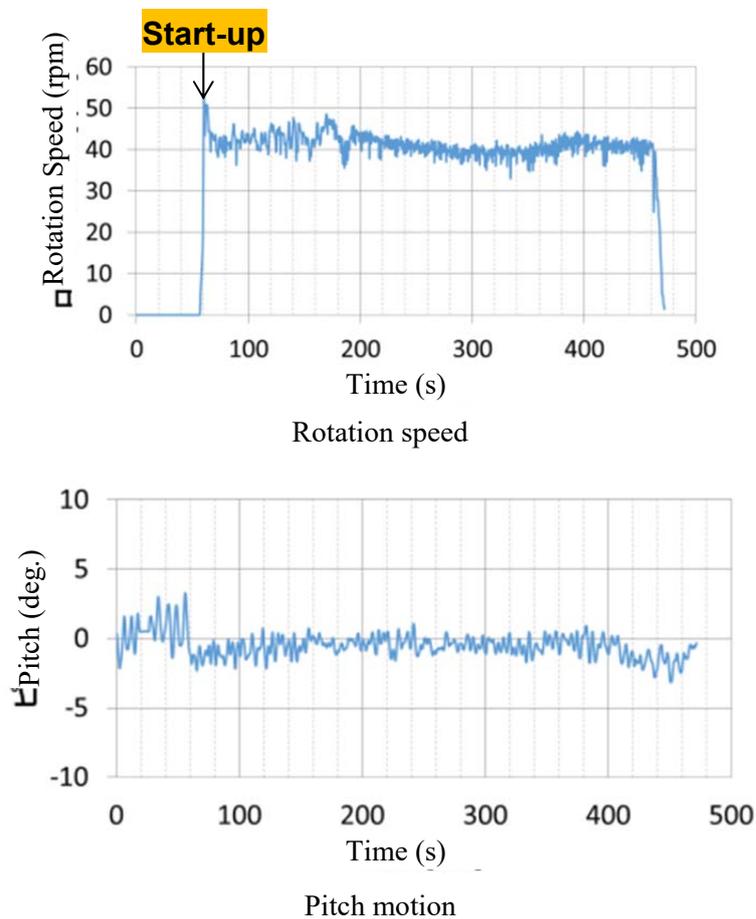


Figure 7. Rotation speed and motion of equipment.

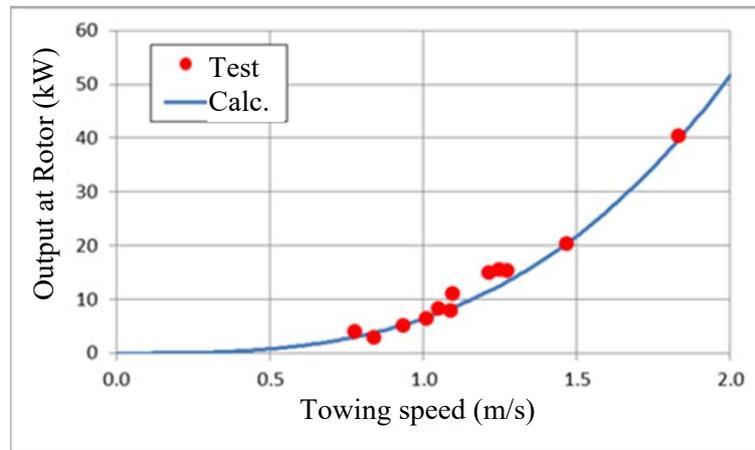


Figure 8. Power curve of the test model.

4. Conclusion

In this research, the components of equipment which extract ocean current energy are studied and its characteristics are confirmed. As a result, following outcomes are acquired,

1. Water lubricated bearing is applied to ocean current turbine and its validity is confirmed
2. In the sea test, stability of ocean current turbine is confirmed in current. And its equipment is able to generate assumed power.

Though we confirmed the validity of all components of the ocean current turbine in model scale, in long operating period it will be required to conduct tests at potential site for evaluation of reliability and stability.

Acknowledgement

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- [1] <https://www.boem.gov/Renewable-Energy-Program/Renewable-Energy-Guide/Offshore-Wind-Energy.aspx> UK Offshore Wind Report 2012, The Crown Estate, 2012.
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