Motion of Twin type Ocean Current Turbine at the time of startup and accident

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Abstract— **Recently, the movement of promoting renewable energy is increasingly growing all over the world. In this paper, ocean current power generation is treated as a potential new generation system. Ocean current turbines need to adopt a floating type because of deep seabed. Since it is only tied by mooring line and there is nothing that restricts movement, it is concerned that this equipment shows unstable motion. Thus, in this study, as a particular situation, the motion at the time of startup and accident is investigated. For the accidental situation, an experiment using a small scale model is conducted and compared with computer simulation. As a result, validity of the computer simulation is shown and by using this simulation it became clear that minor displacement takes place in the accidental case at the realistic scale. With respect to the startup situation, the simulation is improved to revive the motion of the startup and prediction is performed for an experiment which will be carried out in the near future.**

Keywords-component; **Ocean current; Twin type; startup; accident**

I. INTRODUCTION

Ocean current power generation is expected to be a new form of renewable power generation system. Because it utilizes very large flow of sea water, like the Kuroshio, one of the strongest current flows near Japan, it is expected to be a large resource of energy supply in Japan [1]. Furthermore, it can be said that stable energy can be produced from ocean current because of the longer period of fluctuation of ocean current than that of sunlight or wind. Moreover, another strong point is that it is hard to be affected by severe weather such as a typhoon or a storm.

However ocean current turbine has a unique problem. At locations where current speeds are high and steady, the depth of sea is very deep, so it can't be fixed by a column, and we must adopt a floating type. When using ocean current turbines of this type, we need to cancel the torque which is acting on the turbines. Twin-type or contra-rotating type turbines are well known as a method of cancellation. Researches about contra-rotating type turbines are conducted by J.A.Clarke et.al. [2][3] and Takagi[4], and twin-type turbines are studied by Van Zwieten et.al.[5][6].Especially, motion of twin-type turbines at the accidental situations are simulated by Takagi[7].

In this paper, twin-type turbines are adopted, and we check the validity of a computer simulation about an accidental situation by model experiment. Furthermore, for the next experiment, the motion of startup is simulated.

II. SIMULATION METHOD

A computer simulator is developed by Takagi et.al. This simulator calculates equation of motion by Runge-Kutta methods and the force depending on the device is mainly divided into three forces, hydrodynamic force on the main body, forces on the turbine blades, and mooring tensions. As a result, the device movement of 6 degrees of freedom can be calculated. (a definition of 6 degrees of freedom is shown at Fig.1)

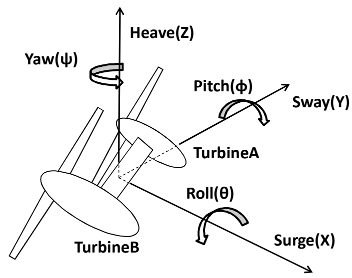

Figure 1 definition of 6 degrees of freedom

A. Hydrodynamic Forces

Hydrodynamic force on the main body and cross-beam is estimated by the 3 dimensions of Boundary Element Method, and drag and lift forces are calculated on the basis of coefficients obtained by experiments.

B. Forces on Turbine Blades

Forces on the turbine blades are estimated by the wing element theory (Fig.2). Lift and drag forces based on the wing element theory are as follows:

$$L = \frac{B}{2}\rho W^2 C_L S \quad (1)$$

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$$D = \frac{B}{2}\rho W^2 C_D S \tag{2}$$

$$S = Cdr \tag{3}$$

Where

$$W = \sqrt{\{V(1-a)\}^2 + \{\Omega r(1+a')\}^2} \tag{4}$$

C : Cord length
ρ : Density of water
C_L : Lift coefficient
C_D : Drag coefficient
a : Axial direction coefficient
a' : Angular induction coefficient
V : Velocity of the current
r : Axis in span direction of blade
B : Number of blade in a turbine

So axial direction force (dN) and tangential direction (dS) is as follows:

$$dN = \frac{B}{2}C\rho W\{C_L \Omega r(1+a') + C_D V(1-a)\}dr \tag{5}$$

$$dT = \frac{B}{2}C\rho W\{C_L V(1-a) - C_D \Omega r(1+a')\}dr \tag{6}$$

Also by using momentum theory, dN and dS is as follow.

$$dN = 4\pi r\rho V^2 a(1-a)dr \tag{7}$$

$$dT = 4\pi r^2 \rho V \Omega a'(1-a)dr \tag{8}$$

Induction coefficients (a and a') are estimated by repeated computation of following simultaneous equations.

$$dN = \pi\rho\sigma W\{C_L \Omega r(1+a') + C_D V\}rdr = 4\pi r\rho V_\infty^2 a'(1-a)dr \tag{9}$$

$$dT = \pi\rho\sigma W\{C_L V - C_D \Omega r(1+a')\}rdr = 4\pi r^2 \rho V_\infty a'(1-a)dr \tag{10}$$

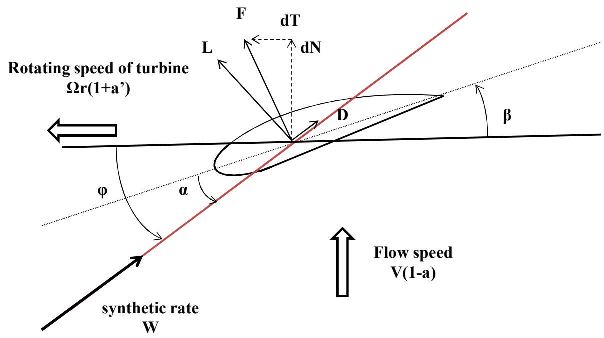

Figure 2 Wing element theory

C. Mooring Tensions

Mooring tensions are estimated by the lumped mass method [8]. Mooring line is regarded as a continuum of lumped mass, and forces (mass, hydrodynamic force, tension) on each particle are estimated by solving the equation of motion. Tension is calculated by the extension deriving from the distance of the particles.

In this paper, as an accident, a situation is estimated where a brake force on the turbine rotation suddenly stops because for example, the gear comes off, and the turbine runs idle.

III. MODEL EXPERIMENTAION

The model used at experiments is shown in Fig.3. The diameter of a turbine is about 0.9 meter. This model has some difference from the real model, for example the pod of this model is slightly longer and it does not have power generators. However, it has motors to apply brake to the turbine as a substitution of generator and the aim of this study is check the motion of the device in the water flow, so the difference would not to be a problem.


Figure 3 Experiment model

The sea flow is relatively made by towing a device moving a carriage (Fig.4). The movement of the device is captured by cameras and calculated by image analysis.

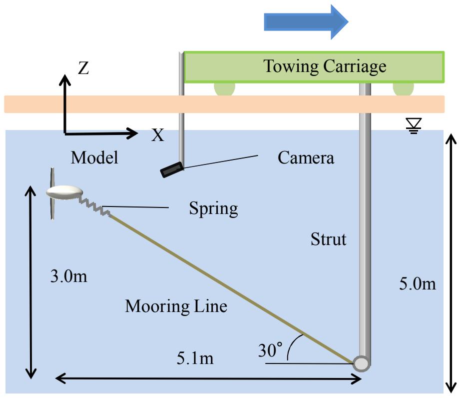

Figure 4 Schematic diagram of the experiment

IV. Result Of Simulation And Experiment

While twin-type ocean current turbine has two turbines that are located far from each other side to side, the motion should be evaluated when right and left thrust force is not equal. If the validity of the simulation is shown by experiments, possibility of accident from thrust unbalance at the realistic scale can be estimated by the simulation.

In the experiments, turbine rotation is controlled by electric brake. At the time of 5 seconds, the brake on the left turbine is turned off. The turbine rotating speed is shown at Fig.5. By the loss of brake force, turbine rotating speed increases rapidly.

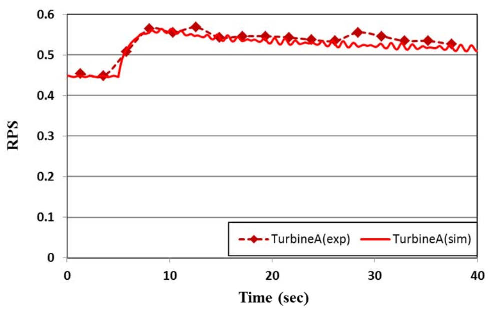

Figure 5 Turbine rotating ratio per second

Fig.6 indicates sum of the thrust force. It seems to reduce a little after 5 seconds and the amount of the reduction is about 0.5N on average. Fig.7 shows the thrust force of the right and left turbines on the simulation. The difference between two turbines is about 0.5N that is 10% of the thrust force.

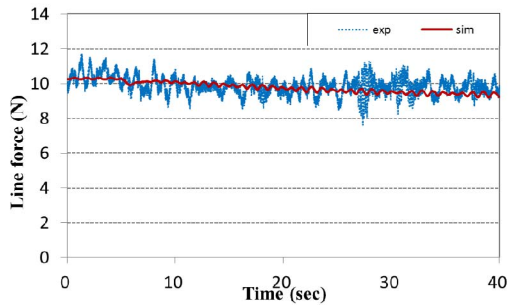

Figure 6 Thrust force on the both turbines

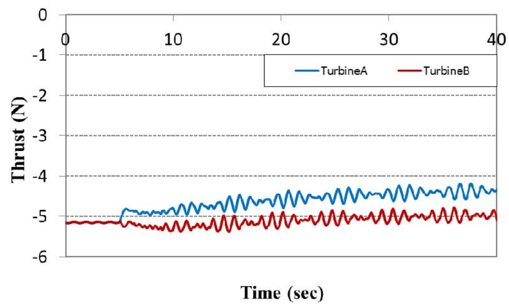

Figure 7 Thrust force on right and left turbines at the simulation

The motion of the device shows a roughly similar tendency between the experiment and the simulation. The device rises and moves to the left because of the reduction of thrust force. Thrust force of the right turbine is superior to that of left turbine, so the right pod towed stronger by the mooring line and rolling or yawing occurs.

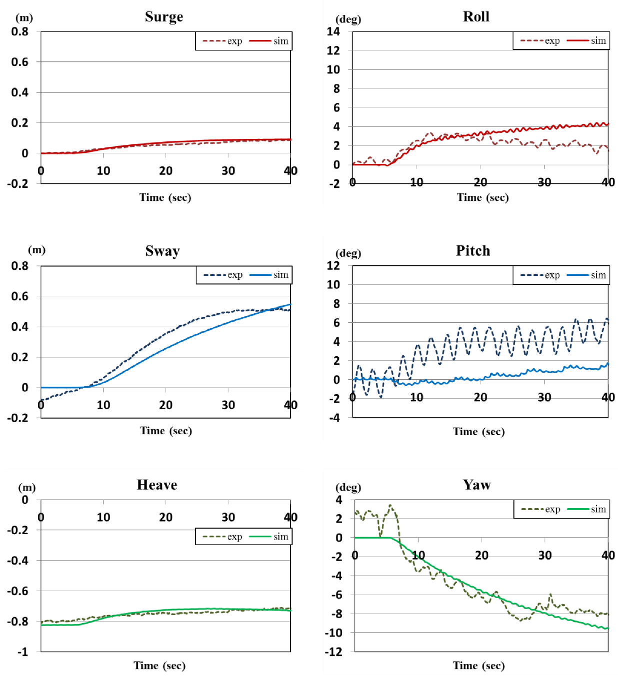

Figure 8 Comparison of motion between the experiment and the simulation

The next step, we try to turn off the brake for a few seconds and turn on the brake again (a slightly stronger brake is used than the former experiment). In this case, tracking of the device is checked. Although the motion is controlled by the turbine pitch control in practice, thrust control by the electric brake is used for checking the tracking motion in the experiment.

At the time of 5 seconds the brake is switched off and at 27 seconds on. The rotating speed is lower when the brake is returned on than at the beginning since inflow velocity is lower because of a forward movement (Fig.9).

Fig.10 and Fig.11 shows thrust force on the turbines.

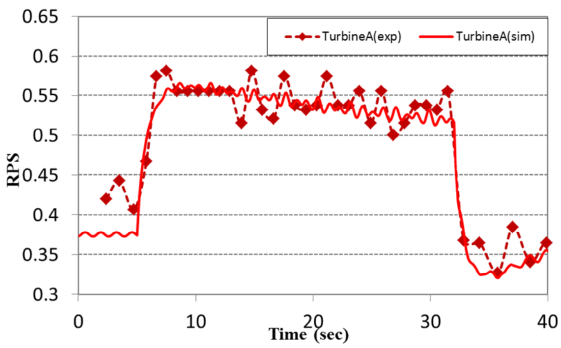

Figure 9 Turbine rotation per second

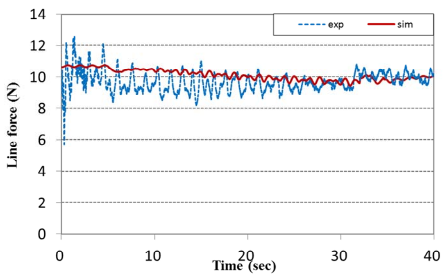

Figure 10 Thrust force on the two turbines

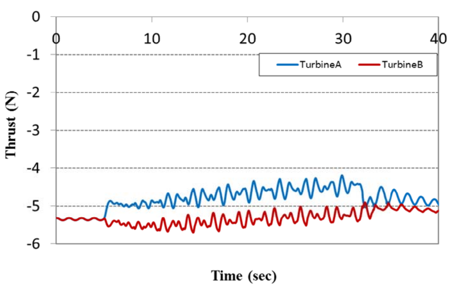

Figure 11 Thrust force on right and left turbines at the simulation

The motion of the device also shows a similar tendency between the experiment and the simulation at this experiment. Movement of returning to default area is confirmed after the brake returned on both at the simulation and the experiment. From this result, the tracking motion is confirmed and it might be lead that thrust control by the turbine blade will be able to control the motion of device in practice.

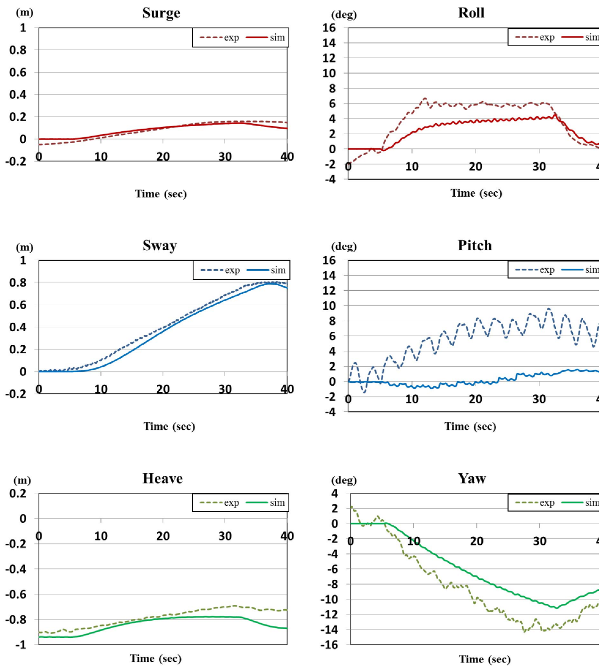

Figure 12 Comparison of motion between the experiment and the simulation

V. Real Scale Simulation At An Accident

While the results of the program used by this study accord with that of the experiments as previously mentioned, it becomes apparent that this numerical calculation method can be used to evaluate the movement of the device. In the following simulation, motion of the device on the actual scale is evaluated. The situation is estimated where one of the turbines stops completely and thrust differs largely between right and left turbines as the most serious accident case.

The turbineA (left side turbine) suddenly stops at the time of 5 seconds (Fig.13), and the thrust force on the turbineA diminishes about 50% (Fig.14).

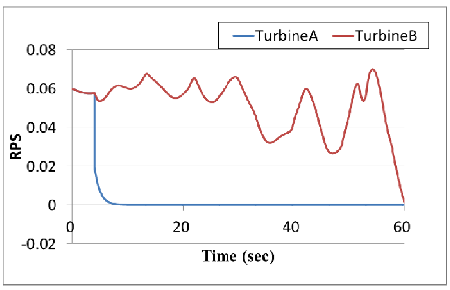

Figure 13 Rotation speed of the turbines

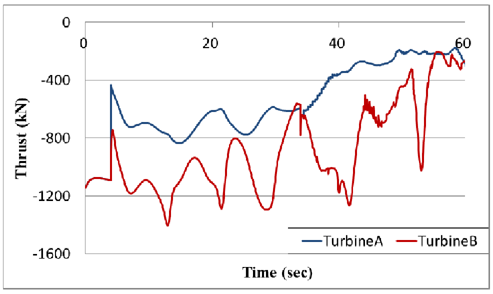

Figure 14 Thrust force on right and left turbines at the simulation

After one turbine stops, the device suddenly rises, and roll and yaw change largely since the right and left thrust balance is broken (Fig.15). However, the displacement of the roll and yaw is about 20 degrees, so it is thought that this case does not lead to a serious accident.

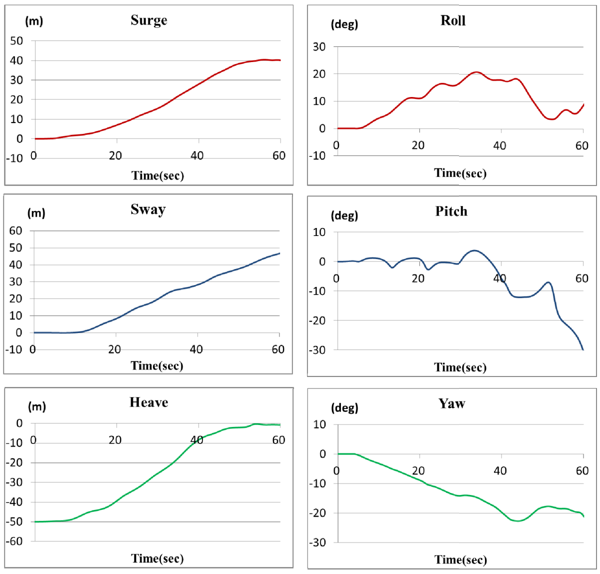

Figure 15 6-degree motions in the situation of the left turbine completely stopped

VI. STARTUP SIMULATION

In the experiments, a new problem occurs; the device floating on the water surface does not sink at the time of startup. So a new system of buoyancy control with draining or pouring ballast water is developed. On the sea surface, seawater is poured into a ballast tank to sink the device and the turbines are fixed until the device completely sinks. After the device reaches target depth, the fixations of the turbines are cancelled and ballast water is drained to control its position. So the next experiment is planned to confirm the motion of sinking at the time of startup. As the preparation for the experiment, the motion of startup is estimated.

While the simulation has been applied to only an underwater device until now, it is improved to be able to reproduce the motion on the sea surface. To control the buoyancy with cancelling moment, two piston tanks are attached at the back and front, and draining about 3.5N of water for each is needed to sink the device completely (Fig.16).

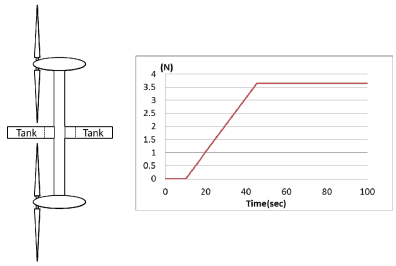

Figure 16 Overview of the device and amount of the drained water

At the time of 10 seconds the tank starts to drain water and after 40 seconds the device starts to sink for about 20 seconds (Fig.17). At the start of sink, small vibration of pitch occurs because of the gap of the mooring angle. However, the movement of the device is relatively small and stable.

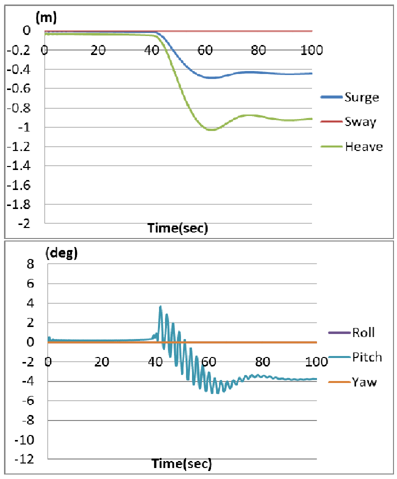

Figure 17 6-degree motions of the device sinking

Then, a situation is examined where the fixations of the turbines are canceled and turbines are started. After the device reaches target depth, the fixations are canceled and few minutes later the brakes which simulated the torque of the generator are put on (In this simulation, the tanks include 2.5N of water in advance).

Rotation speed of the turbines is shown at Fig.18. At the time of 40 seconds fixations are cancelled and the turbines start to race, and at 45 seconds the brakes are put on. Blades are designed as tip speed ratio to be six (Rotation speed is about 2.7 rad/s), but in this situation the rotation speed is lower. It is because the pitch angle of the blades is bigger than it should be as to reduce thrust force. Normally about 10N of thrust force occurs by rotating of the turbine, which leads to sudden sink of the device, so the bigger pitch angle is used to reduce the thrust force.

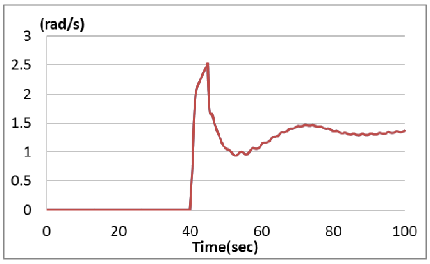

Figure 18 Rotation speed of the turbines

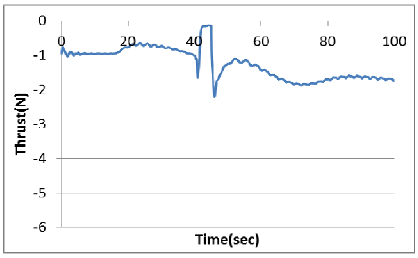

Figure 19 Thrust force on the turbines

The motion of the device is shown in Fig.20. Because the thrust increases by the start of the turbines, the device sinks quickly. The device sinks deeper than target depth, so a gap occurs at mooring angle and the pitch changes about -8 degrees. However, while the difference of thrust is not large, big displacement does not happen.

In reality, after the start of the turbines, combining the blade pitch control and buoyancy control is needed to shift to rated operation with maintaining the position of the device.

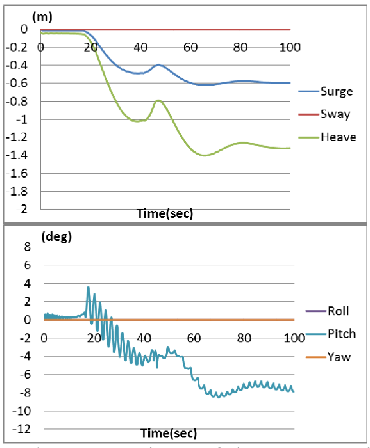

Figure 20 6-degree motions of the startup with turbine rotation

VII. Conclusion

In this study, a comparison between the computer simulation and the experiment is conducted on the accident case. Moreover, by improvement of the simulation the motion at the startup was able to be estimated. The following conclusions are obtained.

・From the comparison between the simulation and experiment when the brake on one side of turbines stops, the validity of the simulation is shown. Furthermore, from the experiment of returning the brake, the tracking motion of the device is confirmed.

・As the most serious accident case in realistic scale, the movement when one side of the turbines completely stops is estimated. Because of the decrease of the thrust, the device suddenly rises, and yaw and roll changes about 20 degrees. However, the displacement of the device is not large and it does not lead to bigger accidents.

・The estimation of movement at the startup is conducted. The result shows relatively stable motion. However, the sink of the device is occurred by the start of the turbines, so the selection of appropriate blade pitch angle seems to be significant.

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