Mooring and Power Cable System for Current-Turbine

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***Abstract*—This paper discusses device stability and cable stress of "Twin Turbine Marine Current Generator". To confirm the stability of the device by V-shaped mooring system, computer simulation and model experiment are performed. Subsequently, using results of the computer simulation in a severe situation, the stresses applied to the dynamic cable are calculated with "OrcaFlex9.6a". The results of computer simulation and model experiment shows that the device can be moored stably with V-shaped mooring system even if current velocity or direction changes suddenly, and the computer simulation is useful to evaluate motion of the device. Furthermore, the result of cable stress calculation with OrcaFlex9.6a shows that no cable stress closes in on breaking stress if cable configuration is appropriate, and a configuration that fixes the cable to the mooring line at multi points is the safest style in the candidates calculated in this paper.**

Keywords*— *Current Turbine; Twin Floater; Mooring Line; Dynamic Cable; Stability; Cable Stress

I. INTRODUCTION

Ocean current power is one of the large marine renewable energy resources especially in strong ocean streams such as The Gulf Stream and Kuroshio. In order to generate power from ocean current, "Twin Turbine Marine Current Generator" with single point mooring system, which is said to be able to supply sufficiently cheap and relatively stable power, is proposed.

Research on floating type ocean current turbine has just begun. K.Takagi[1] proposed the concept of twin-turbine marine current generator and contra-rotating type marine current generator. A.Cribbs [2] proposed the numeric model of a mooring system for an ocean current turbine. K.Sakata et.al [3] performed motion calculation of twin-turbine marine current generator.

It is considered that V-shaped mooring system (Fig.1) is suitable for twin turbine current generator from the viewpoint of economy. Although motion stability in the system will influence its feasibility, it has not yet been studied how the device moves in case of sudden change of current velocity and direction. Furthermore, stresses applied to dynamic cable also remains unknown, even though stresses for the cable can be one of the major obstacles if the stresses are so large as to break it.

Under these circumstances, this paper aims at confirming the stability of the device when exposed to sudden current change and examining forces applied to the power cable. To achieve these aims, firstly, computer simulation and model experiment is performed to confirm the stability of the device. After that, using results from the simulation, the forces applied to the dynamic cable are calculated with "OrcaFlex9.6a".

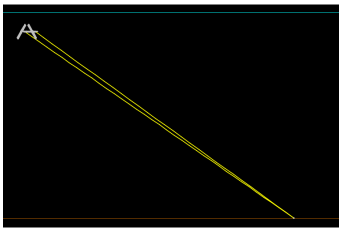

Figure 1. V-shaped mooring system

II. SIMULATION METHOD

A computer simulation, which estimates the motion of twin turbine marine current generator, is developed by K.Takagi et.al. This simulation calculates equation of motion by Runge-Kutta methods and the force applied to the device is mainly divided into three forces, hydrodynamic forces on the main body, forces on the turbine blades, and mooring tensions. As a result, the device motion of 6 degrees of freedom can be calculated.

A. Hydrodynamic Forces

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

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B. *Forces on Turbine Blades*

Forces on turbine blades are estimated by the wing element momentum theory.

C. *Mooring Tensions*

Mooring tensions are calculated according to 3 dimensional lumped mass method developed by T.Nakajima et.al.[4]. In this method, mooring lines are regarded as a continuum of lumped mass and forces (gravity, hydrodynamic force, tension), and are calculated on each particle (Fig.2). Tension is calculated from the distance of particles and dynamic calculation is performed by Houbolt's method.

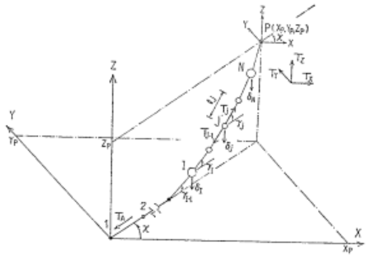

Figure 2. Lumped mass model [4]

III. MODEL EXPERIMENT

The model used in the experiment is shown at Fig.3. The diameter of the turbine is about 0.9 meter (1/50 of real scale). At the end of the mooring line, a spring is installed to make natural period of the model line correspond to it of real scale mooring line. Water flow is made relatively by towing a device from a moving carriage (Fig.4). The motion of the device is captured by cameras installed on the towing carriage and calculated by image analysis.

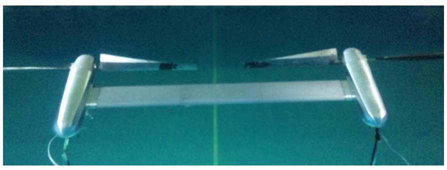

Figure 3. The model used in the experiment

Cases performed in the experiment are as follows.

A. *Uniform Current*

To confirm that the model motion is stable in calm conditions, experiment in uniform current is performed at first. The current velocity is firmed at 0.20 m/s, 0.22 m/s, and 0.25 m/s, which correspond to approximately 1.41 m/s, 1.56 m/s, and 1.77 m/s in real scale.

B. *Sudden Change of Current Velocity*

To check model motion in case of sudden change of current velocity, experiment in this case is performed. In this case, velocity of the towing carriage is adjusted to 0.2 m/s at first, and 10 seconds after, the carriage is accelerated rapidly from 0.2 m/s to 0.25 m/s.

C. *Sudden Change of Current Direction*

The carriage can move not only x-direction, but also y-direction. With this function, current direction change can be made relatively. In this case, velocity of the towing carriage is adjusted to 0.2 m/s to x-direction at first, and after 5 seconds, the carriage is accelerated rapidly to the direction of y axis up to 0.1 m/s. After 9 seconds motion for y-direction, the carriage y-direction motion is stopped while the x-direction motion continues (Fig.5).

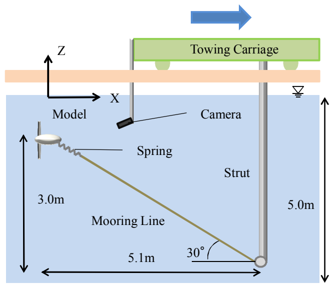

Figure 4. Schematic diagram of the experiment

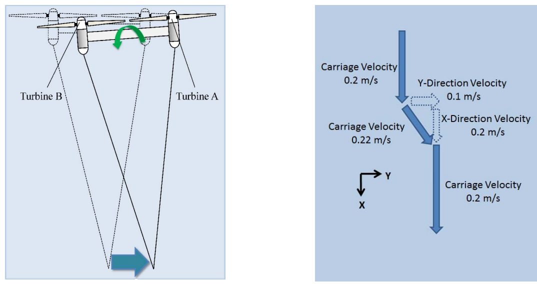

Figure 5. Situation of Current Direction Change

IV. RESULT OF SIMULATION AND EXPERIMENT

A. *Uniform Current*

Through the experiment in uniform current, it is confirmed that the model is stably moored in this condition.

B. *Sudden Change of Current Velocity*

Through the experiment in the case that sudden change of current velocity occurs, it is confirmed that the model moves down to equilibrium position because of increase in thrust force and becomes stabilized at the new equilibrium position. Furthermore, from the comparison of computer simulation and experiment, it is also confirmed that the computer simulation result agrees very well with the experiment result in this case (Fig.6). Although it is rear case that current velocity changes 25% increase in short term, it is verified that the device moves calmly to the new equilibrium position and no unstable motion occurs in this case.

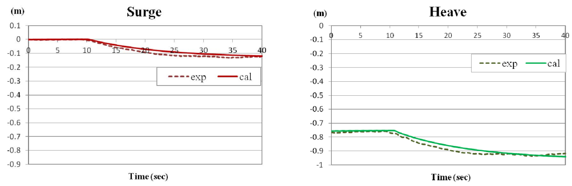

Figure 6. Comparison of surge and heave movement between experiment and computer simulation

C. *Sudden Change of Current Direction*

Through the experiment in the case that sudden change of current direction occurs, it is confirmed that the model moves along the current because of weather vane function. The function occurs because thrust force and mooring tension force is so strong that they are the dominant factors in motion of the model. From the comparison of computer simulation and experiment (Fig.7), it is also confirmed that the computer simulation result agree with the experimentation result.

However, it cannot be said that the agreement between calculation and experiment results in sway and yaw is perfect. Because, in the experiment, rotating speed of turbine B is a little faster than computer simulation (Fig.8) and it is considered that this is the reason why sway and yaw motion in experiment shows faster recovery to the original equilibrium position than computer simulation.

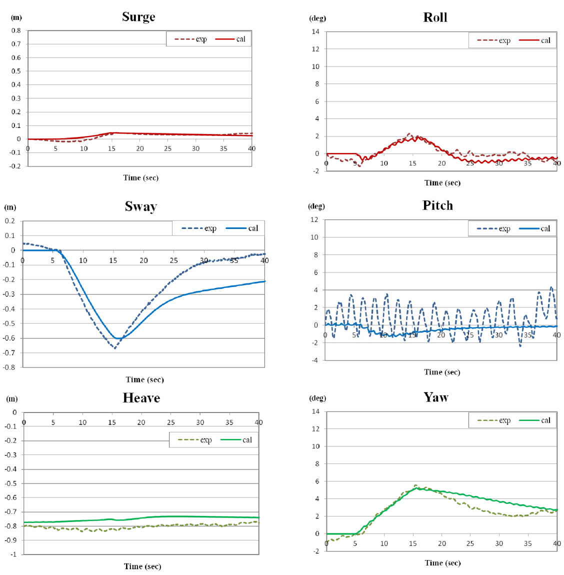

Figure 7. Comparison of movements between experiment and computer simulation

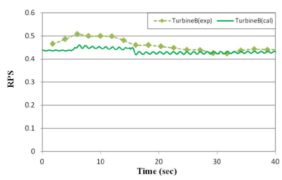

Figure 8. RPS of turbine B in experiment and computer simulation

V. CABLE STRESS CALCULATION

In this chapter, methods and results of cable stress calculation are explained. First, four cable configuration candidates are introduced. Next, calculation conditions are stated. And finally, results of the calculation and discussion are mentioned. The calculation is performed by using 'OrcaFlex9.6a'.

A. *Cable Configuration Candidates*

Cable configuration has to be decided before calculating cable stress, because it greatly influences the cable stress. In this paper, four configurations are introduced as important candidates and calculation in this chapter is performed with them as targets. The configuration candidates are shown in Fig.9.

Free catenary style is a style that simply hangs down the cable. It is assumed easy to install. Single point fixed style is a style that fixes the cable to the mooring line at single point. Multi points fixed style is a style that fixes the cable to the mooring line at multi points. Floater Installed style is a style that installs a floater on a part of dynamic cable. The floater buoyancy should be decided not to collide with the generator turbine and mooring line.

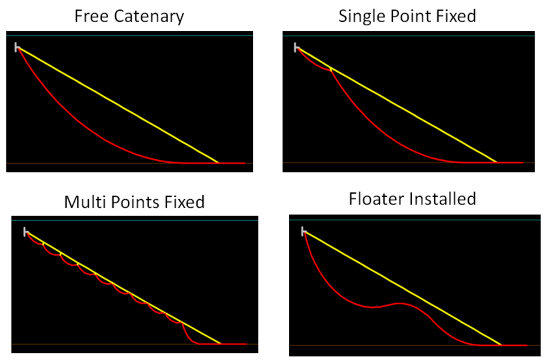

Figure 9. Dynamic cable configuration candidates

B. *Calculation Conditions*

Because it is known that static stresses are estimated small enough in each style, dynamic analysis is performed in this paper. As the dynamic motion of current turbine generator, simulation result would be used. In order to estimate cable stresses in severe situation, motion in the case of accident is used in this calculation. Simulation when one of the twin turbines completely stops is performed by T.Gonoji .et.al.[5] and the motion is estimated as Fig.10. In this paper, this motion is simulated in OrcaFlex9.6a and cable stresses in this situation is estimated.

Specification of dynamic cable and mooring line is determined referring to estimation by De-Regt Marine Cables and contents of 'Anchor Manual 2010' (Vryhof Anchors). Cable breaking tension is set at 800 kN and breaking curvature is set at 0.83 rad/m in this paper.

In addition, current velocity near sea surface is set to 1.5 m/s, which declines according to depth and current direction is normal to the turbine blade.

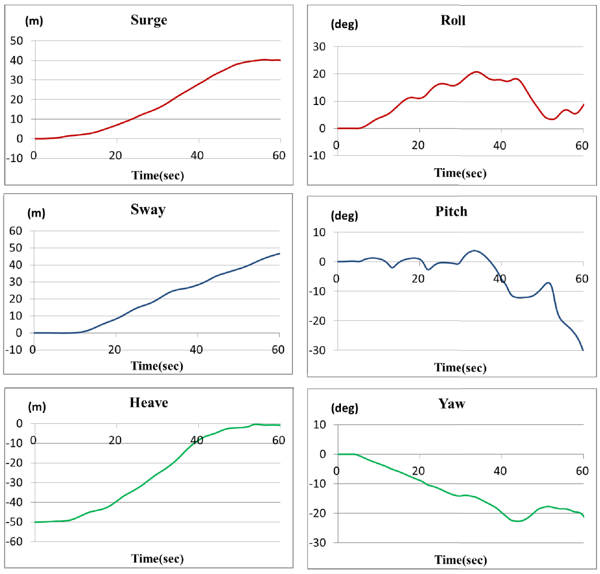

Figure 10. 6-degree motions in the situation of the left turbine completely stopped [5]

C. *Results and Discussion*

Max stresses in the cable stress calculation are shown in Fig.11. These results show that effective tension is relatively high in free catenary style and low in multi points fixed style and floater installed style, which is considered to be effects of cable weight. It is also confirmed that curvature is relatively high in multi points fixed style.

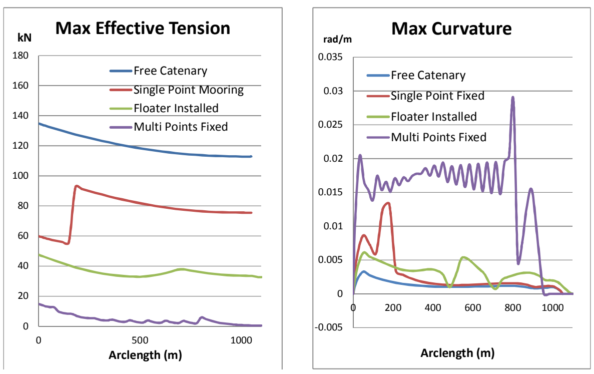

Figure 11. Maximum tension and curvature in dynamic analysis

These results are compared to cable breaking stress, and ratios between the breaking stresses and calculated maximum stresses are shown as Table 1. This result shows that no stress closes in on breaking stress in each style and multi points fixed style is the safest style in the candidates.

Table 1. Ratio between breaking stress and calculated maximum stress of each style

	Free Catenary	Single Point Fixed	Multi Points Fixed	Floater Installed
Quotient of Breaking Tension and Calculated max Tension	5.9	8.6	53.9	16.8
Quotient of Breaking Curvature and Calculated max Curvature	231.0	62.7	28.8	95.1

VI. CONCLUSION

In this paper, model experiment and computer simulation is performed to confirm the stability of the device with V-shaped mooring system when current velocity or direction changes suddenly. After that, cable stress calculation in severe body motion is performed.

The results of model experiment and computer simulation of the stability study shows that the device can be moored stably in the uniform current, the device moves calmly to the new equilibrium position even if the current velocity changes suddenly, and the floater returns to the flow direction by weather vane function when the flow direction changes. Furthermore, the motion simulation program for twin turbine marine current generator developed by K.Takagi et.al is useful to evaluate six freedom motion of the device.

The results of cable stress calculation in severe situation shows that no stress closes in on breaking stress even if turbine accident occurs and a configuration that fixes the cable to the mooring line at multi points is the safest style in the candidates calculated in this paper.

Further study should be done to confirm the cable stress in the situation when current direction changes 360 degrees or more, because it is known that there is turnover of current direction once several years even in Kuroshio stream, which is considered to be a cause of strong stress to the cable.

ACKNOWLEDGMENT

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