論 文 の 内 容 の 要 旨

論文題目　A Simple Calculation Method for Turbine Blade Load in Shear Flow
（せん断流中におけるタービンブレード荷重の簡易推定法）

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1. Introduction

Renewable energy including wind energy and ocean energy are developing rapidly in recent years. Compared with the electricity generation by conventional fossils, the wind generation is becoming increasingly competitive with development and commercialization of offshore wind turbines and wind farms. Compared with wind energy, ocean energy has its advantage as long-term perspective and it can be more accurately predicted. Generally, tides and currents are recognized as two principal forms of ocean energy. Many tidal energy devices are developed for energy extractions.

The tidal current turbine is currently leading technology that is likely to be accepted by industry and investors to adopt the ocean renewable energy. For Japan, the ocean current turbine is of great importance since Japan has one of the strongest ocean currents in the world, the Kuroshio Current.

The floating ocean current turbine has been proposed as a new way to harness the current energy. Japan has piloted on the field ocean current turbine by the concept design and field tests. It is expected that the research work on ocean current turbines will help to develop the industry of the ocean energy generation, which will make a contribution to the higher energy security of Japanese society.

For the tidal current turbine, most of the technology is from the study of the wind turbine which has clear international standards and commercial software. There are some differences in thrust, aspect ratio and solidity between tidal current turbines and wind turbines. These differences are also challenges for ocean current turbines.

In addition, a shear profile of flow velocity is discovered when analyzing the measured data from ADCP near potential locations in Japan[1]. Shear flow is a significant challenge to the ocean current turbines because it could cause fluctuations in the inflow of the blades, and thus altered the bending moments on the blade roots of the ocean current turbine[2]. Moreover, little study has been made on the study and experiment of hydrodynamic shear flow. For the successful application of ocean current turbines, it is necessary to get accurate calculation of power output and structural loads in design, installation, and maintenance.

2. BEM model

In the turbine industry, BEM theory is widely used as a computational tool to predict the blade loads and rotor power performance. It has been discussed by many scholars that the BEM model can be an effective developing tool for the design of tidal turbines and ocean current turbines[3].

In practical, seldom is the case the only the classical BEM theory is used for the calculation or design of turbines blades. As for the tidal current turbines, several principal corrections were applied with BEM theory to improve the accuracy. The corrections include tip loss correction and hub loss correction, thrust correction and correction after stall[4,5].

We have compared with the experiments of other scholars[3], and the results in Fig 1 show good agreements.

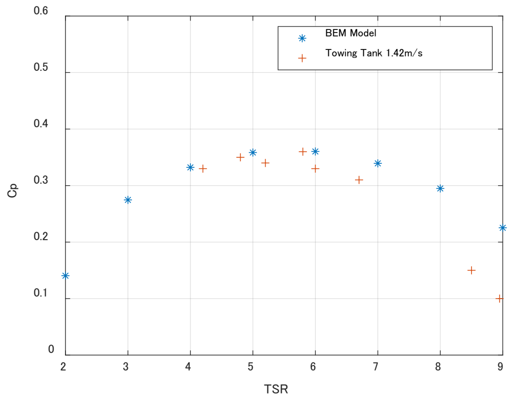

Fig. 1a Comparison of power coefficient between experiment and simulation

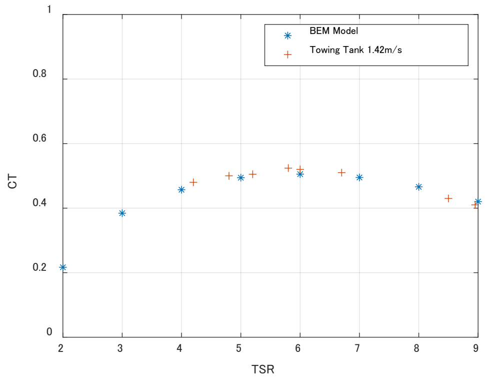

Fig. 1b Comparison of thrust coefficient between experiment and simulation

The effect of shear flow on structural loading is important, in that shear flow can lead to fluctuations in bending moments. However, BEM model tends to overestimate the amplitudes of the fluctuations in the out of plane bending moment at the blade root, which will affect the accuracy of the load prediction.

3. Experiments

Several experiments to generate shear flow and to measure model turbines in shear flow have been conducted in this study. We have inserted three designed grids of parallel bars to generate shear flow a circulating water channel. While many scholars have studies shear flow in wind tunnels, it is the first time to generate shear flow in water. We used the empirical solidity equation from Rose's study, and got approximately linear shear flow with our designed shear profile. The shear profile of one typical case shows as Fig 2.

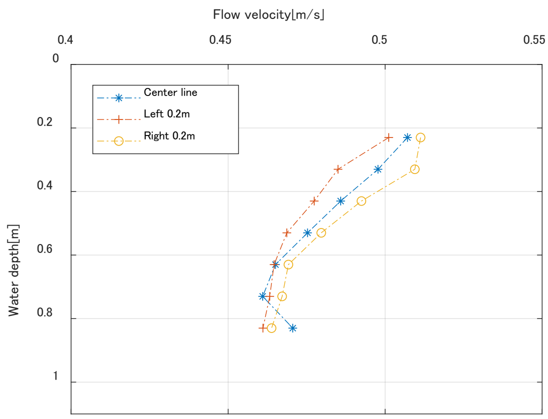

Fig 2 Measured flow velocity with water depth of experimental data

Fig 3 1/50 scale model of two bladed horizontal axis ocean current turbine

A 2-bladed horizontal axis ocean current turbine model of 1/50 scale with a 0.88m diameter was designed and the blades used aerofoil NACA0012 and were made from the aluminum alloy, as depicted in Fig 3. The model was tested in the shear flow generated in the circulating water channel. We used thrust and torque sensors to measure the rotor shaft toque and thrust for turbine performance analysis. Load cells were used to measure the out of plane bending moments at one blade root. It is the first time that out of plane bending moments at one blade root of the ocean current turbine model are measured.

To get the accurate measurement of the model turbine in uniform flow, the same model turbine was tested in the towing tank in the Chiba station of the University of Tokyo. The rotor was centered at 0.2 m below the free surface. The model turbine is fixed with the carriage of the towing tank, which can be moved at a constant speed. The torque and out of plane bending moment and in plane bending moment at one blade root were measured in same averaged flow velocity with the cases in the circulating water channel.

Blockage correction is applied for the measured loads in the circulating water channel. After blockage correction, the measured bending moments of uniform flow in the circulating water channel agreed well the case of uniform flow in the towing tank. The blockage correction is considered reliable for the experimental data.

When compared with our experimental results in uniform flow, the accuracy of the developed theoretical BEMT model for design and parametric studies is satisfactory, while overestimating the power coefficient at high tip speed ratios.

4. Unsteady airfoil theory

BEM theory assumes rigid turbine blades and steady inflow velocities and hydrodynamics. The mathematical model of the unsteady thin airfoil theory, based on the Theodorsen's theory[6] is hence introduced and combined with BEM theory as a simple numerical simulation method for the design of blade performance of horizontal axis ocean current turbines.

The results provide more satisfactory simulation compared with original BEM theory when calculating the out of plane bending moments at the blade root of ocean current turbines in shear flow condition, as shown in Fig 4. The accuracy of original BEM theory to predict structural loads in shear flow is enhanced by adding the unsteady effect.

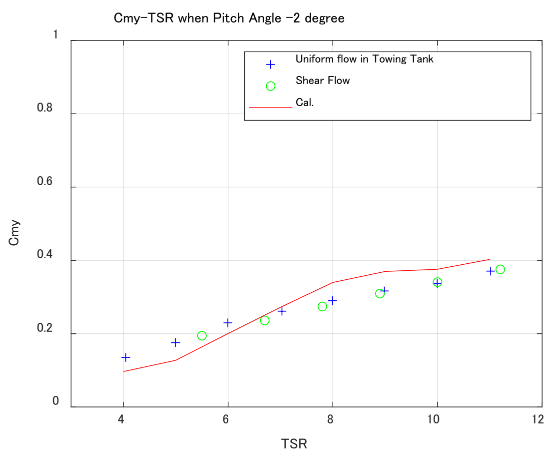

Fig 4a Comparison of averaged Cmy when pitch angle is -2°

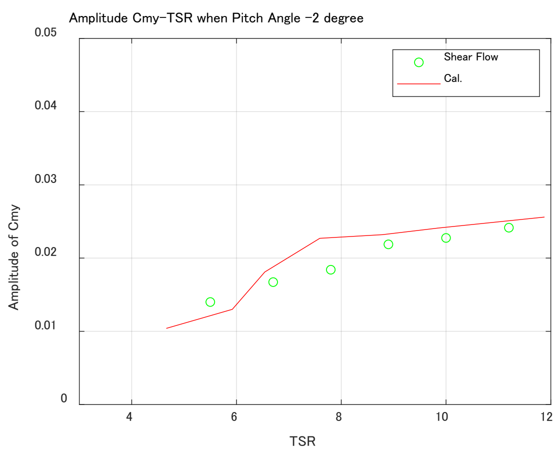

Fig 4b Comparison of Cmy amplitude when pitch angle is -2°

The comparisons validate that the numerical model which combines the BEM theory with Theodorsen's function can offer a satisfactory prediction for the unsteady condition for full-scale ocean current turbines as a simple and fast model that can be easily combined with a motion simulator.

5. Discussion on important parameters in turbine design

It is found that several significant parameters affect the calculation of ocean current turbines.

Attack angles decrease with the rise of tip speed ratios. Dynamic stall happened in low tip speed ratios, thus the accuracy of stall model is of importance when the tip speed ratio is low.

Tip loss and hub loss are significant for ocean current turbines. Tip loss model is of great importance in that loss affect the induction factors of blade sections near the blade tip, where influence the out of plane bending moment at that blade root most in the calculation model. Tip loss and hub loss model also decrease the attack angle of blade sections near the hub and the blade tip.

Although for 3-bladed turbine model by Bahaj et al., the drag coefficients from XFoil don't affect the estimation of power coefficient to a large extent, it is known that drag coefficients in XFoil are underestimated. We found that the drag coefficients affect the power coefficients for our ocean current turbine model, especially for high tip speed ratios, as shown in Fig 5. There is a possibility that we can improve the effect of drag coefficients if we use accurate values.

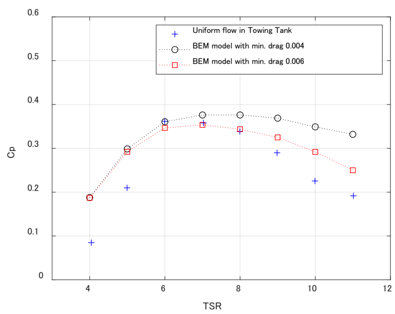

Fig 5 Comparison of power coefficients with TSR when pitch angle is 0°

Summarizing all the results, we concluded that the numerical model we developed can be used as a simple and fast method for ocean current turbine calculation. It can work well with the motion simulator for future development of ocean current turbines.

Reference

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