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The effects of surge motion of the floating platform on hydrodynamics performance of horizontal-axis tidal current turbine

Liang Zhang, Shu-qi Wang, Qi-hu Sheng, Feng-mei Jing*, Yong Ma

College of Shipbuilding Engineering, Harbin Engineering University, Harbin 150001, China

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ABSTRACT

Under practical operation conditions, hydrodynamic characteristics of floating horizontal-axis turbine are affected by the wave-induced motion response of the floating platform for the turbine system. In this thesis, CFX software is adopted to analyze the hydrodynamic performance of the turbine in constant inflow with the turbine being forced vibrating and to study how the hydrodynamic performance of the turbine is influenced by surge frequency, surge amplitude and speed ratio. Based on the simulation data from CFX, axial damping coefficient can be obtained by least square fitting the time-varying axial force curves of surging turbine. The simulation results demonstrate that compared with turbine only rotating in constant inflow, shaft loads and energy utilization ratio of the surging turbine experience oscillations respectively; the oscillation amplitudes of these two parameters have a positive correlation with the frequency and amplitude of the surge and speed ratio; the frequency and amplitude of the surge have little impact on axial damping coefficient but this coefficient is positively proportioned to the rotational speed of the turbine. The results of this study can provide data to study motion response of floating platform for floating tidal current turbine system and control design of the output electricity.
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1. Introduction

Energy issues not only have significant impacts on global economy, but also are closely related to ecological environment and greenhouse effect. Therefore, an increasing number of nations all over the world begin to develop clean and renewable energy resources, among which tidal current energy [1] is of huge potential. Tidal current energy is characterized by sustainability, high energy density, predictability and offshore location, and time changes like season and year have marginal effects on energy output of this energy resource.

Within tidal current energy station, tidal current turbine [2–4] is an essential component, the hydrodynamic performance of which directly determines the efficiency of the power station. At present, the main theories used to study hydrodynamics of turbines of this kind are flow tube theory [5], vortex theory [6], CFD [7] (computational fluid dynamics) and experiments [8,9]. However, experiments are not massively used because of their high expenditure. Based on momentum theorem, the simulation model of flow tube theory is excessively simplified, such as neglecting the induced velocity perpendicular to the inflow, leading to inaccurate simulation results when solving the side forces of the turbine, unsteady performance and transient loads of the turbine or blades. The momentum theorem might be divergent if the speed ratio exceeds a specific figure. Compared with flow tube theory, the free vortex model of vortex theory based on potential theory could accurately calculate turbine transient loads and interference between blades of the rotor or a blade and free vortex, and simulate unsteady effects like blade rotation effect and pressure distribution details on blade surface. But the blades of the turbine will experience large angle of attack when the turbine operates under mediate or small speed ratio, which means that the blade loads calculation are of low accuracy due to severe dynamic stall. CFD solves governing equation within the entire flow field, the result of which can be stored for further study and more flow details can be captured. Besides, full scale model can be simulated using this method. Because of these advantages, currently CFD is extensively used in research concerning tidal current turbines [10].

Tidal current energy isn't a new idea for us, but the basic theory studies for it are relatively less, while most of the efforts are dedicated to the experimental study of the performance of tidal energy turbine. Batten et al. [11] studied the influence of profile, twisted angle, conical degree and pitch angle for the power coefficient and cavitation number in 2006. It was found that the cavitation can be minimized even avoided by choosing appropriate pitch angle or higher camber. Bahaj et al. [8] experimented a

* Corresponding author. Tel.: +86 0451 82569359.
E-mail addresses: wshq1205@163.com, jingfengmei@hrbeu.edu.cn (L. Zhang).

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three-blade tidal energy turbine with diameter 0.8 m and profile NACA63-8xx in cavitation cave and towing tank in 2007. In the cavitation cave experiment, the pitch angle of the blade was set 15–30°, the pitch angle of the hub 20–25° and the flow velocity 0.8–2 m/s. In the towing tank experiment, the immerged depth of the blade tip was set 0.19 D to 0.55 D and the yawing angle 0–30° from the axis. It was discovered that the power coefficient of turbine reached its peak when the pitch angle of the hub was 20°. The power coefficient decreased by 10–15% when the immerging depth changed from 0.55 D to 0.19 D because of the influence of free surface. Maganga et al. [12] experimented a three-blade turbine with diameter 0.7 m, flow turbulence 8%–25%, yawing angle −10 to 20°, immerging depth 0.94 D, 1.37 D and 2.04 D in a sealed circulation channel in 2010. This experiment discovered that when the flow was highly turbulent, the power coefficient and thrust coefficient decreased by 9%. It was also discovered that the performance of tidal energy turbine would decrease greatly at larger yawing angle, while the change of depth wouldn't have much effect on its performance. Barltrop et al. [13] studied the influence of wave for the performance of tidal energy turbine by measuring the average torque and thrust in one regular wave length of a three-blade, 0.16 m-diameter, S814-profile, 66.5 mm-maximum chord tidal energy turbine in 2007. In the experiment, the angular velocity was kept constant and four waves with different frequency and the same wave height was measured. The study showed that the average parameters are the same with or without wave, but the transient values of them were greatly different, which would have a great effect on the fatigue and life span of the full-scale turbine. In 2010, Gallway [14] did the same experiment on a three-blade horizontal axis tidal turbine. The diameter of the model was 0.5 m and the experiment was conducted in regular wave in deep water (wave length/wave height = 0.4). The result of this experiment was similar to Barltrop's: the variation of thrust was about 37% and torque 35%, which means the varying load on the blade will obviously accelerate the fatigue of turbine, posing a challenge to the design of the full-scale tidal turbine. In 2010, Zhang Liang [15] experimented a two-blade horizontal tidal turbine with diameter 0.7 m, profile S809, flow velocity 1.2 m/s to 2.7 m/s, pitch angle 0–30°, yawing angle 0–20°, immerging depth of axis 0.5 m, 0.7 m and 0.9 m in the ship towing tank in Harbin Engineering University. The results of this experiment clearly showed the performance of the horizontal axis tidal turbine in favorable current, deviated current and unfavorable current. This experiment also showed the effect of changing the immerged depth and pitch angle on the performance of turbine, and the effect of the surface condition.

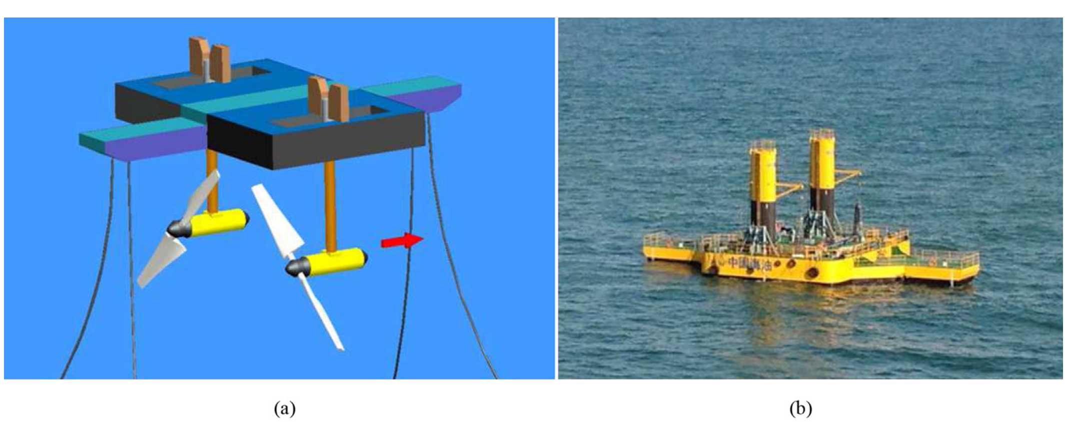
In summary, all the conducted studies are about horizontal axis tidal turbine revolving around the fixed axis. However, in practice, the floating platform of the floating tidal current power station (shown in Fig 1, the floating tidal current power station was designed by Harbin Engineering University for CNOOC and installed at Zhaitang island, Qingdao city, China, in June 2013. The floating platform was fixed by 4 mooring lines, the rated power of the tidal current power station was 2*100 KW, the diameter of the turbine is 12 m, the rated flow velocity is 1.7 m/s) has wave-induced motion [16], thus, the turbine also moves with the platform and the speed distribution at the turbine is altered, which affects the hydrodynamic performance of the turbine. Consequently, it is essential to study the hydrodynamic performance of the turbine under motion conditions. However the variation of the hydrodynamic of the turbine will have influence on the motion of the floating platform (such as, the motion amplitudes and frequencies), therefore, the motion of the floating platform and the hydrodynamic force of the turbine have interaction effect. This paper studied the influence of the motion of the floating platform on the hydrodynamic force of the turbine, the interaction effect between the motion of the platform and the hydrodynamic force will be the further research of author.

This thesis, using CFX, studies the hydrodynamic performance of the horizontal-axis turbine being compulsorily oscillated under the constant inflow condition. Analysis like how it is affected by different frequencies, amplitudes of the surge and rotational speed is conducted. Axial damping coefficient and axial added mass coefficient are derived through fitting the time-varying hydrodynamics curves using least square fitting method [17], which provides vital data for research on wave-induced response of floating support structure for tidal current turbines and designs for control mechanisms of electricity output.

2. Numerical simulations

2.1. Basic theories

The surge speed of the turbine is represented as u (unit: m/s), the inflow speed U (unit: m/s), diameter of the turbine D (unit: m), number of blades N and rational speed of the turbine ω_T. In addition, the inflow direction is defined as the forward direction of Z axis. Compared with the loads parallel to the inflow direction, loads perpendicular to it are marginal and the important factor considered here is the power coefficient. Therefore, the all the simulations in this thesis neglected the loads perpendicular to the inflow direction.



(a) (b)

Fig. 1. 3D conceptual diagram (a) and physical diagram (b) of floating tidal current power station.

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