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Experimental study of hydrodynamic performance of full-scale horizontal axis tidal current turbine*

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Abstract: In this paper, experiments of both the model turbine (1 kW) and the full scale (10 kW) turbine are carried out in a towing tank and a basin, respectively, and the test of the full scale turbine on the sea is conducted. By comparison between the model turbine ($D = 0.7$ m) and the full scale turbine ($D = 2.0$ m), it is shown that the maximum power coefficient increases with the increase of the diameter of the turbine. The test results on the sea are used to study the hydrodynamic performances of the horizontal axis turbine, and provide a basis for the design. Experimental results can validate the accuracy of the numerical simulation results.

Key words: Tidal current energy, horizontal axis turbine, model test, full scale test, sea trial

Introduction

The oceans cover more than 70% of the earth's surface and offer huge energy resources for the production of electricity and/or fresh water[1-3]. The ocean energy is available in various forms, including tidal wave, tidal current, thermal energy, salinity gradients and biomass[4]. The tidal current energy technology shares many similar fundamental characteristics with the wind energy. Like a wind turbine, the tidal current turbine converts the kinetic energy of the fluid into the electrical energy. However, due to the difference of the working environment, there are some distinct phenomena of the tidal current turbine from the wind turbine, including cavitations, free surface, and wave-induced velocity gradient, etc.[5]. For example, compared with the wind turbine, the tidal current turbine has an advantage that those reversing gravity loads, such as the buoyancy, can be used to balance the weight, which is very important for the horizontal-axis tidal current turbine. Given these considerations, it is necessary to study the characteristics of the tidal current turbine, which is of interest for designers.

The investigation of the tidal current energy is a classic topic in recent decades and many fundamental issues were studied by both numerical and experimental approaches. In the design of the horizontal axis turbine, many parameters should be considered, including loads, depth and cavitation occurrence, so the experiment is an effective means to explore the characteristics of the horizontal axis turbine. This paper presents only the experiment work on the horizontal-axis tidal current turbines, and the experiment work on the vertical-axis tidal current turbines were described in the literature[6,7].

A number of experiments were conducted to cha-

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racterize the turbine performance. Bahaj et al.[8,9] conducted experiments under conditions of different airfoils, pitches and yaws, blade cavitations and twin-rotor interactions, to validate blade element momentum models. Wang et al.[10] conducted experimental and numerical study under different rotor preset angles. Maganga et al.[11] conducted experiments in a closed-loop water tunnel, examining the effects of the inflow turbulence intensity, varying from 8% to 25%, the yaw angle ranging from -10° to 20°, and the depth beneath the free surface, including observations at $0.94D$, 1.37D and $2.04D$ in a channel of $3.14D$ deep. Galloway et al.[12] carried out small-scale mesh disk rotor simulators to study the structure of the wake, specifically with regard to the depth. Tests were conducted in a flume of 0.3 m deep with disk of 0.1 m in diameter. The depth, measured from the center of the disk, was set to $0.33D$, $0.50D$, $0.66D$ and $0.75D$ and the velocity deficit was examined from a distance of $20D$. The velocity deficit was found to be higher for shallow settings, and at the deepest settings the disk was considered as a submerged obstruction. Barltrop et al.[13] conducted experiments in a towing-tank using a three-bladed turbine with the diameter of 0.4 m and featuring an S814 airfoil cross-section.

To the authors' knowledge, there are few experimental studies of the full scale turbine, which serves as a challenge. The full scale turbine experiment is very expensive while the sites that can be used to test the turbine performance are hard to find; because the loads on a full scale turbine are larger than those on a model turbine, the requirements for the test equipment are very severe, which imposes another difficulty for the full scale turbine experiment. However, the full scale turbine test data are important for the study of the horizontal axis tidal current turbine. In this paper, the model turbine experiment is conducted in a towing tank and the full scale turbine is examined in a deep basin, moreover, the full scale turbine is tested in the real sea. The relationship between the model turbine and the full scale turbine is studied by comparing the power coefficient. Experimental results could be used as the basis for the design of the horizontal axis turbine, and also could be used to validate the accuracy of numerical simulation results.

As we all know, in an experiment, if the Froude number is made to satisfy the requirements, it is very difficult to make the Reynolds numbers also satisfy the requirements[14,15], so the scale effect is unavoidable in the experiment. In order to reduce the experiment error, the larger the model, the better the test result will be. However, the large model will increase the cost and make the requirements for the test equipment more complex. The large model is better to be tested in a large basin where the blockage effect can be reduced. Therefore, this paper makes a comparison of results between the 1 kW model turbine ($D=0.7$ m) and the 10 kW full scale turbine ($D=2.0$ m), which would be significantly important for analysis of the scale effect on the horizontal axis tidal current turbine.

1. Turbine experiments

The turbine used in the experiment is a two-bladed horizontal axis turbine, where the diameter of the model turbine is 0.7 m and the diameter of the full scale turbine is 2.0 m. The model experiment is carried out in the towing tank of Harbin Engineering University (HEU), the full scale turbine test is carried out in a basin of HEU, and the test of the full scale turbine on the sea is carried out in the Daishan Island of China.

Table 1 Particulars of turbine blades

r/R	Chord/m	Pitch distribution/ $^{\circ}$	Thickness, σ/ m
0.20	0.48	23.39	0.10
0.26	0.46	19.18	0.10
0.30	0.44	16.41	0.09
0.35	0.43	14.13	0.09
0.39	0.41	12.25	0.09
0.43	0.40	10.67	0.08
0.48	0.39	9.33	0.08
0.52	0.37	8.18	0.08
0.57	0.36	7.19	0.07
0.61	0.34	6.33	0.07
0.65	0.33	5.57	0.07
0.70	0.32	4.89	0.07
0.74	0.30	4.29	0.06
0.78	0.29	3.76	0.06
0.83	0.27	3.27	0.06
0.87	0.26	2.84	0.05
0.91	0.25	2.44	0.05
0.96	0.23	2.07	0.05
1.00	0.22	1.74	0.05

1.1 *Description of blades*

To improve the utilization efficiency of tidal energy, the blade element momentum (BEM) based Wilson model is applied to the design of the horizontal tidal turbine[16]. The blades of the turbine are developed by Institute of Ocean Renewable Energy System of HEU, based on the simplified wind theory and the Glauert vortex theory[17,18].The blades are