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Experimental investigation into the effects of blade pitch angle and axial distance on the performance of a counter-rotating tidal turbine ☆

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ABSTRACT

In order to investigate the influence of blade pitch angle and axial distance on the performance of the counter-rotating type horizontal-axis tidal turbine (HATT), a series of experiments were conducted in a wind tunnel under different installation conditions. The blades were designed based on the blade element momentum (BEM) theory, and the effects of configuration factors were actualized in two aspects: different combinations of the front and rear blade pitch angles and different axial distances of dual rotors. The test results indicate that the proper increase of blade pitch angles and axial distance can enhance the performance of a counter-rotating turbine by increasing the peak C_P (power coefficient) value and widening high C_P value area. However, more experiments are still needed in order to investigate the relationship between C_P and axial distance under small blade pitch angles more precisely. Flow field investigation is also required to understand the wake structure and intensity around the blades with small pitch angles. The result in the wind tunnel is a reference for the experiment in the water tunnel.
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1. Introduction

Renewable energies have been playing an increasingly important role in modern civilization in order to cope with the increasingly serious environmental and resource issues. Various kinds of technologies for commercial scale generation of electrical power have become the targets of industrial and academic research worldwide. Compared with land-based renewable energy technologies, there exists larger potential in the sea-based ones, among which the tidal turbine possesses some obvious advantages. The gross kinetic energy in tidal currents is extremely large and it appears regularly and predictably in perfect tune with the relative motion of the Earth, Moon and Sun (Fraenkel, 2002). Hence, the horizontal-axis tidal turbine, known as HATT, is well worth investigation.

There is some degree of similarity between the design of HATTs and wind turbines, but fundamental differences also exist in Reynolds number, stall characteristics and the possible occurrence of cavitation which require further research (Batten et al., 2006). In order to achieve better performances, the concept of counter-rotating has been put forward. For wind power it may be difficult to justify the added complexity of the rotor configuration, but the potential advantages of near-zero reaction torque, near-zero swirl, high relative rotational speeds as well as increased power output are particularly significant in a marine context (Clarke et al., 2007).

In the research of conventional HATTs, the Sustainable Energy Research Group at the University of Southampton has made great contributions (Batten et al., 2008; Bahaj et al., 2007) including the development of a 800 mm model turbine based on traditional BEM theory and experiment studies in a cavitation tunnel and a towing tank. Previous investigations of counter-rotating type HATTs have also obtained some satisfactory results. Lee et al. (2015) simulated the streamlines of the dual rotors numerically and studied the influence of the distance between the two rotors on turbine performance. It was observed that the flow separation occurred closer to the trailing edge as the distance increased. Jung et al. (2005) investigated the aerodynamic performance of a 30 kW counter-rotating turbine using the quasi-steady strip theory and considered the near wake behavior of the front rotor. The effectiveness of counter-rotating turbines over conventional ones was demonstrated. In the research of Clarke et al. (2007), a counter-rotating marine turbine was designed using modified blade element modeling theory and tested in a towing tank, in

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Nomenclature

A	rotor area
a	axial velocity reduction factor
b	tangential velocity reduction factor
C_d	drag coefficient
C_l	lift coefficient
C_N	axial thrust coefficient
C_P	power coefficient
C_T	tangential force coefficient
C_M	rotational torque coefficient
dD	drag force
dF	total force
dL	lift force
dT	axial force
dQ	angular momentum
P	power
r	blade element radius
U	mean flow speed
V	relative velocity
α	angle of attack
β	section pitch angle
ρ	fluid density
σ	rotor solidity
φ	angle of relative flow
Ω	angular velocity of rotor
ω	angular velocity of flow behind rotor
D_R	diameter of rear rotor
D_F	diameter of front rotor

Abbreviation

BEM	blade element momentum
HATT	horizontal-axis tidal turbine
TSR	tip speed ratio

which high-frequency blade loading data showed the anticipated performance, and flow visualization of the wake verified the lack of swirl behind the turbine. Kanemoto et al. (2000) and (2010) developed the "Counter-Rotating Type Hydroelectric Unit" which is composed of the tandem runners and the peculiar generator with the double rotational armatures. Usui et al. (2013a) and (2013b) applied experimental researches on the turbine performances with both mooring and pillar systems and investigated the effects of the propeller rotation on the sea surface. Huang et al. (2014) developed a CFD model for the design of the counter-rotating type HATT which achieved good agreements with the experiment results, and studied a multi-objective numerical method for the optimization of front blade pitch angles of the dual rotors (Huang and Kanemoto, 2015).

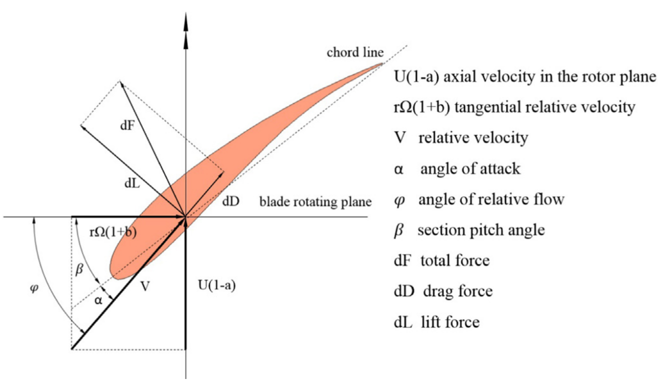

Fig. 1. Force and velocity distribution for single blade element.

This paper mainly discussed the effects of blade pitch angles and axial distance on the performance of a counter-rotating type HATT designed by the blade element momentum (BEM) theory. A series of experiments were conducted in a wind tunnel under different configuration conditions and the relationship between power coefficient and tip speed ratio was achieved. Further experimental tests will be carried out in a water tunnel.

2. Blade element momentum (BEM) theory

Blade element-momentum (BEM) theory is one of the most commonly used methods for calculating induced velocities on

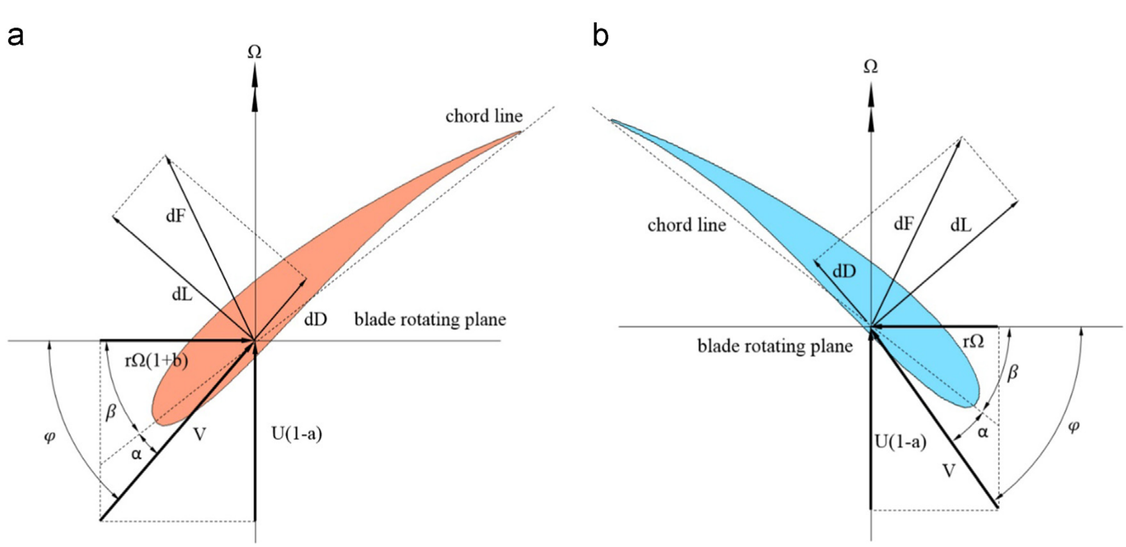

Fig. 2. Detailed information of force and velocity for the counter-rotating blades (a) front blade and (b) rear blade.

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