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Experimental Investigation of Helical Tidal Turbine Characteristics with Different Twists

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Abstract

The helical tidal current turbine was studied and reported its performance and characteristics for free water flow electric turbine development. The scale model of tidal turbine was built in dimension as: 0.5m and 0.6m of diameters and 1.25m in length; the turbine cross section blade was the symmetric NACA0020 with a 0.07m chord length, and there were 3 blades with the helical angle of 120°, 135°, and 150°. The model was tested in a towing tank (1.46m width, 3m depth and 45m length). The rotation and torque of the turbine was measured under various tow velocity settings, while power and power efficiencies under various tip speed ratios and helical angle velocities were presented. The characteristics obtained from this experiment provide useful information for the design and development of helical tidal current electrical turbine.

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Keywords: Hydrokinetic turbine, Helical tidal turbine, Gorlov turbine, Ocean energy, Renewable energy

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1. Introduction

Helical turbine was firstly developed by Prof. Alexander M. Gorlov from Northeastern University, called Gorlov Helical Turbine (GHT) [1]; such turbine was designed based on the Darrieus type and composed of symmetry foil and using the helical shape in length direction of the blade to increase turbine torque. The GHT can perform high revolution (rpm) under low current velocity without cavitation and torque fluctuation; moreover, the overall efficiency is also higher than normal Darrieus turbine [2]. Therefore, this turbine is always used for tidal electric turbine. The major advantage of such turbine is installation benefits such as simple mechanical coupling, shallow water installation ability, and it can be installed wherever the water current direction leads. These pros makes such turbine can be placed where the horizontal turbine cannot [3]. However, detailed data for GHT has little to show the several turbine geometries compared to characteristics.

This article presents the performances and characteristics of helical tidal turbines at different turbine diameters and blade helical angles. The model is towed in towing tank at various speeds, while all parameters such as rpm and torque are recorded. The characteristic obtained from this experiment will be useful for design and development of helical tidal current turbine.

2. Theory

Tidal energy is expressed in the form of kinetic energy (*KE*). Since the mass (*m*) is moved by velocity *V* m/s, the kinetic energy can be displayed as equation 1.

$$KE = \frac{1}{2} m V^2 \tag{1}$$

Since the tidal velocity has unit as mass per time, one can replace m in equation 1 by $\dot{m}$ the kinetic energy of current will transform to hydrokinetics (*P*) as shown in equation 2.

$$P = \frac{1}{2} \dot{m} V^2 \tag{2}$$

Nomenclature

A	Rotor area (m^2)
c	Turbine chord (m)
C_p	Power coefficient (-)
D	Turbine diameter (m)
L	Turbine length (m)
n	Number of blade (-)
P	Rotor power (W)
P_w	Hydrokinetic power (W)
Q	Rotor torque (N-m)
R	Rotor radius (m)
TSR	Tip Speed Ratio (-)
V	Current velocity (m/s)
δ	Helical angle (◦)
ρ	Fluid density (kg/m^3)
Ω	Rotational speed of rotor (rad/s)
σ	Solidity (-)

The ratio between current velocity (*V*) and cross section area (*A*) can be expressed as water mass velocity per time (equation 3).

$$\dot{m} = \rho A V \tag{3}$$

where ρ is the water density kg/m^3. Replacing $\dot{m}$ in equation 3 into equation 2, the maximum of water flow power is obtained as shown in equation 4.

$$P_w = \frac{1}{2}\rho A V^3 \tag{4}$$

The main purpose of such turbine is converting kinetic energy to mechanical energy which is similar to wind turbine concept [4]. The converting formula is shown in equation 5

$$P = \frac{1}{2} C_p \rho A V^3 \tag{5}$$

where ρ is the water density, A is the turbine swept area, V is the current velocity, and C_p is the turbine power coefficient. In theory, the maximum of efficiency is not over 59.3% according to Betz limit [5]; however, the power coefficient is directly proportion to the tip speed ratio (*TSR*): the ratio between tip speed and current velocity as shown in equation 6. The *TSR* also depends on blade shape and number of blade [4].

$$TSR = \frac{\Omega R}{V} \tag{6}$$

where Ω is rotational speed of turbine (red/s), and R is the turbine radius. The solidity (σ) is a value that significantly affects the performance of turbine as shown in equation 7

$$\sigma = \frac{nc}{\pi D} \tag{7}$$

where n is the number of blade, c is turbine chord length and D is diameter of turbine.

The power coefficient of turbine can also calculated by ratio between mechanical power and kinetic energy as shown in equation 8

$$C_p = \frac{2Q\Omega}{\rho A V^3} \tag{8}$$

where Q is the rotor torque (N-m).

3. Experiment Setup

Model tests were carried out in the towing tank at department of research and develop of irrigation department of Thailand [6] which had the following working section specification:

Length	43 m
Width	1.5 m
Depth	3 m
Maximum carrier speed	2 m/s

The three bladed systems were used in the present investigation. Model was composed of symmetry foil NACA0020, 0.07m chord length (c), 0.5m and 0.6m of diameter (D) and 1.25m length. There were 3 different helical angle (δ) designs of blade which were 120°, 135°, and 150° as shown in figure 2(a). The model with set of mechanical brake load, torque transducer and tachometer assembled with structure as shown in figure 2(b), while picture of the installed turbine in the towing tank was shown in figure 3.

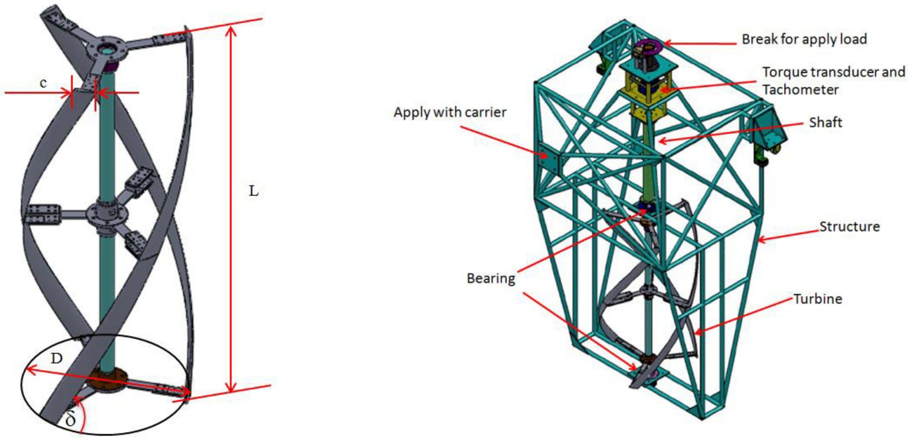

Fig. 1. (a) The schematic of helical current turbine; (b) Experimental apparatus

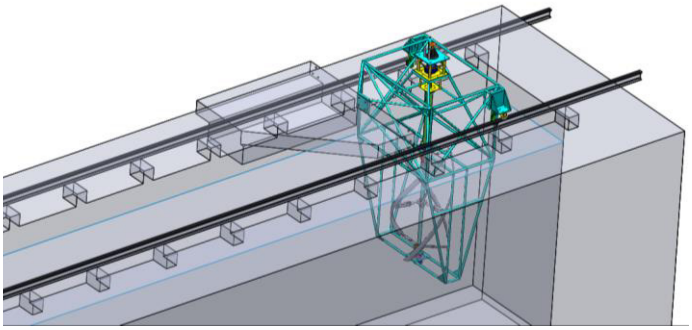

Fig. 2. Towing tank with helical current turbine gantry mounted with carrier.

4. Result

The towing speed was set from 0.9 – 1.655 m/s for each diameters and angle set of blades. The solidity (σ) of model was 0.134 and 0.111 for 0.5m and 0.6m of diameter, respectively. Firstly, the model diameter of 0.5m and helical angle of 120° was attached to the turbine and tested. The turbine power which was product of torque (Q) and Ω was in proportion to a cube of the current velocity as shown in figure 4(a). The power coefficient derived from equation 8 was plotted against tip speed ration (*TSR*) as shown in figure 4(b). The maximum efficiency of various velocities, 20~25%, was occurred around *TSR*≅2.2. The same procedure was also carried out for the angle 135° and 150° helical angle blade as shown in figure 5 and 6 respectively. Finally, the model diameter of 0.6m and helical angle of 120°, 135° and 150° was tested. The turbine power and power coefficient were plotted as shown in figure 7, figure 8 and 9 respectively. The maximum efficiency of various velocities, 19~26%, was found around *TSR*≅2.5. The experimental data confirmed that the 135° helical angle for 2 cases had good characteristics.

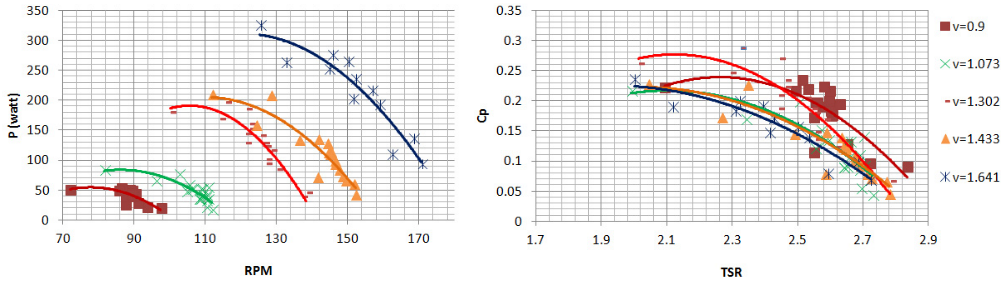

Fig. 3. D=0.5 m and δ=120º (a) Power output; (b) Power Coefficient

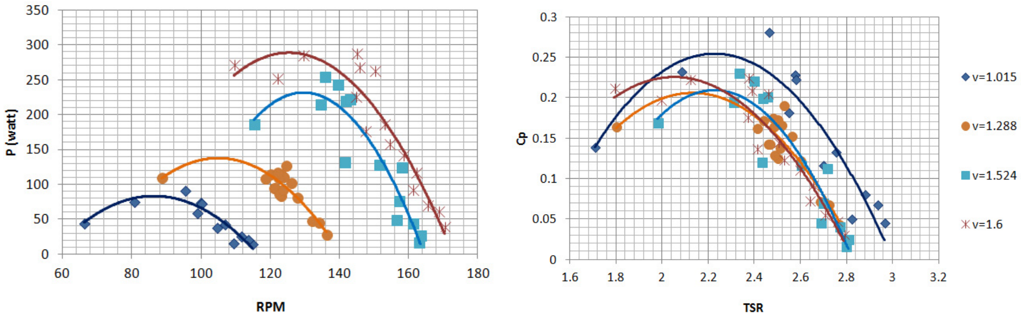

Fig. 4. D=0.5 m and δ=135º (a) Power output; (b) Power Coefficient

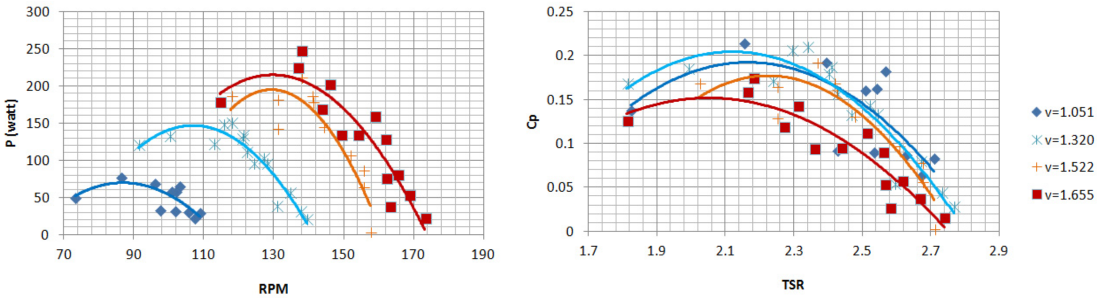

Fig. 5. D=0.5 m and δ=150º (a) Power output; (b) Power Coefficient

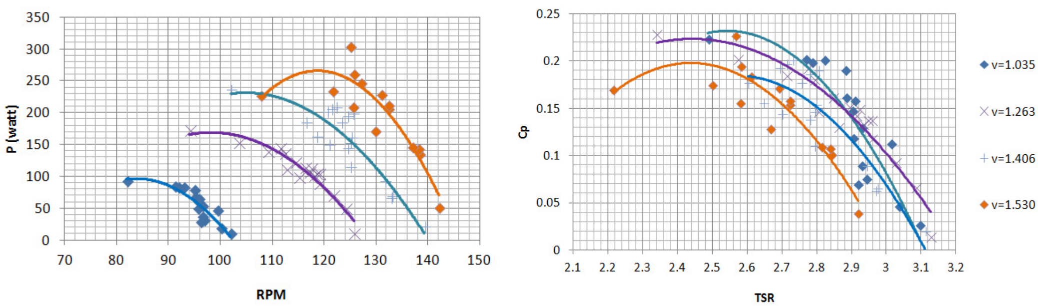

Fig. 6. D=0.6 m and δ=120º (a) Power output; (b) Power Coefficient

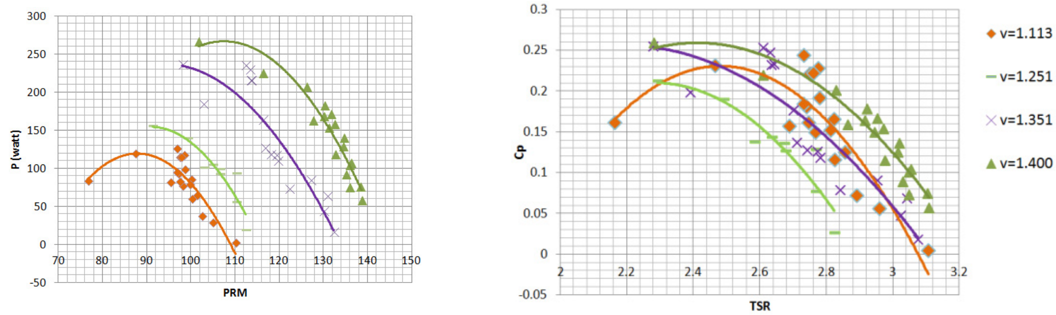

Fig. 7. D=0.6 m and δ=135° (a) Power output; (b) Power Coefficient

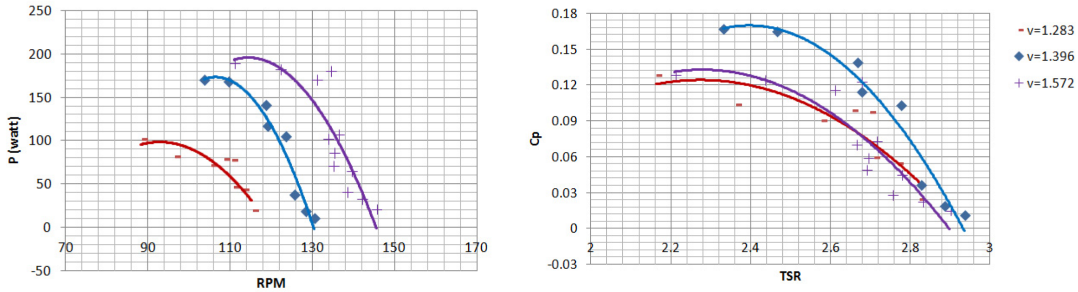

Fig. 8. D=0.6 m and δ=150° (a) Power output; (b) Power Coefficient

5. Conclusion

The helical tidal current turbine was investigated its characteristics. The experiment was conducted using various turbine models. The results indicated that helical angle has influence to turbine efficiency, while the turbine solidity had effect only to *TSR*. At helical angle was $\delta = 135^o$, the system showed better efficiency for $\sigma = 0.134$ at TSR≅2.2 and for $\sigma = 0.111$ at TSR≅2.5. The experimental results suggested useful design information for tidal current electrical turbine development.

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