DEVELOPMENT OF A DUCTED HORIZONTAL AXIS MARINE CURRENT TURBINE ROTOR

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I humbly dedicate this pearl of my effort to…

my beloved husband,

Mohd Yusairi B. Mohd Yusoff

my beloved parents,

Abdul Aziz B. Abdullah & Rohani Bt Baba

and my beloved siblings

who have supported me in many ways.

ALLAH bless all of us

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ABSTRACT

Marine current energy resource has great potential to be exploited on a large scale because of its predictability and intensity. This energy can be extracted by various kinds of device, one of which is Horizontal Axis Marine Current Turbine (HAMCT). This thesis describes the development of a HAMCT to extract marine current energy suitable for Malaysian sea. The marine current speed in the Malaysian sea is quite low, averaging only about 1 m/s (2.0 knots). Presently available HAMCT designs are not suitable for low current speeds since a large turbine is needed while the blade diameter is limited to water depth. In this thesis, the problem is circumvented by placing the rotor in a duct, which helps to increase the water speed. The HAMCT rotor and duct were developed using Computer Aided Design (CAD) technique and analysed using Computational Fluids Dynamics (CFD) software. For the rotor, simulations were carried out with two conditions; 'without duct' and 'with duct'. A 4.884 m diameter rotor with various numbers of blade and design tip speed ratio (TSR) were developed. The duct was developed in two different shapes, in which each shape has 5 variations of cylinder length. From the simulation of ducts, the current speed at the entrance of the cylinder is taken into account because the rotor is placed inside the cylinder. Thus, the maximum current speed generated was used in the 'with duct' simulation condition, while 'without duct' condition is when the rotor is simulated using actual current speed. The output power and performance of rotor are investigated using two methods; CFD simulation results and Blade Element Momentum (BEM) theory. It was found that the rotor model 4B2 is the greatest rotor because of its highest power coefficient for both methodst. The output power of the ducted turbine was significantly enhanced compared to the one without duct, which is 546.931W and 4250.012W by BEM. Validation was carried out by comparison to Batten work and it shows that the shapes of curves for both works are similar which this is sufficient to validate that the results of this project are genuine and acceptable.

ABSTRAK

Tenaga arus marin mempunyai potensi yang besar untuk digunakan pada skala yang besar kerana kebolehanramalannya dan kesungguhannya. Tenaga ini boleh diserap menggunakan pelbagai jenis alat, salah satu daripadanya adalah Horizontal Axis Marine Current Turbine (HAMCT). Tesis ini menghuraikan pembangunan HAMCT untuk menyerap tenaga arus marin yang sesuai dengan laut Malaysia. Halaju arus marin di Malaysia adalah rendah, secara puratanya 1m/s (2 knots). Pada masa ini, reka bentuk HAMCT yang sedia ada tidak sesuai untuk halaju arus rendah kerana turbin yang besar diperlukan, sementara diameter bilah terhad terhadap kedalaman air. Di dalam tesis ini, masalah ini diatasi dengan meletakkan rotor di dalam saluran, di mana ia membantu menambahkan halaju air. Rotor HAMCT dan saluran telah dibangunkan menggunakan teknik Computer Aided Design (CAD) dan di simulasi menggunakan Computational Fluids Dynamics (CFD). Bagi rotor, simulasi dilakukan dalam dua keadaan, ‘tanpa saluran’ dan ‘dengan saluran’. Rotor berdiameter 4.884 m dengan pelbagai bilangan bilah dan Tip Speed Ratio (TSR) telah dibangunkan. Saluran telah dibangunkan dalam dua bentuk yang berlainan, di mana setiap bentuk mempunyai 5 panjang silinder yang berlainan. Dari simulasi saluran, hanya halaju arus pada pintu masuk silinder yang diambilkira kerana rotor diletakkan di dalam silinder. Halaju maksima yang terhasil akan digunakan untuk simulasi ‘dengan saluran’, manakala keadaan ‘tanpa saluran’ adalah apabila rotor disimulasi menggunakan halaju asal. Kuasa keluaran dan pekali kuasa rotor diselidik menggunakan 2 kaedah; keputusan simulasi CFD and teori BEM. Didapati rotor model 4B2 adalah rotor terbaik kerana kecekapan rotornya yang paling tinggi bagi kedua-dua kaedah. Kuasa keluaran turbin bersalur didapati bertambah berbanding turbin tanpa saluran iaitu 546.931W dan 4250.012W dari BEM. Pengesahan keputusan dilakukan dengan membandingkannya dengan hasil kerja Batten dan didapati bentuk graf bagi kedua-dua kerja adalah sama, dimana ini menunjukkan keputusan projek ini adalah tulen dan boleh diterima.

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AR	-	Aspect Ratio
a	-	Axial induction factor
a'	-	Angular induction factor
B	-	Number of blade
c	-	Chord length
C_d	-	Drag coefficient
C_l	-	Lift coefficient
C_p	-	Power coefficient
D	-	Drag
D_{cyl}	-	Cylinder diameter
D_{hub}	-	Hub diameter
D_{noz}	-	Nozzle diameter
D_{rotor}	-	Rotor diameter
F	-	Force
F_x	-	Tangential force
F_Θ	-	Radian force
I	-	Inertia of an annulus
L	-	Angular moment
L	-	Lift
L_{cyl}	-	Cylinder length
L_{noz}	-	Nozzle length

m	-	Mass flow rate
P	-	Output power
p	-	Pressure
p_1	-	Pressure at upstream of rotor or initial velocity
p_2	-	Pressure before reach rotor
p_3	-	Pressure after through rotor
p_4	-	Pressure at downstream of rotor or final velocity
Q	-	Tip loss correction factor
R	-	Radius of the rotor
r	-	Rotor radii
TSR	-	Tip Speed Ratio
TSR_r	-	Local tip speed ratio
T	-	Torque
V	-	Velocity
V_1	-	Velocity at upstream of rotor or initial velocity
V_2	-	Velocity before reach rotor
V_3	-	Velocity after through rotor
V_4	-	Velocity at downstream of rotor or final velocity
W	-	Relative velocity
α	-	Angle of Attack
β	-	Relative velocity angle
ϕ	-	Current angle
γ	-	Velocity angle
φ	-	Blade twist angle
λ	-	Scale factor
θ	-	Blade angle
ρ	-	Density
σ'	-	Local solidity
ω	-	Angular velocity of blade wake
Ω	-	Angular velocity of blade

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CHAPTER 1

INTRODUCTION

1.1 Background

Mankind has been utilizing renewable energy sources since the dawn of civilization through different technologies. Today, renewable energy sources play a significant role in the world and supply more than 14% of the total global energy demand [1]. The common factor for the development of renewable energy technologies in the 1970s is it was based on concern that there would be shortages of fossil fuel, but of course today the concern is for the damage to the environment from greenhouse gases if continue to burn even the known reserves of oil in their entirety [2].

Renewable energy sources, most notably, wind energy, solar energy and small scale hydro power schemes have undergone major development. One other form of renewable energy which has attracted great interest is marine current energy, which can be extracted by a device called marine current turbine. This energy resource has a great potential to be exploited on a large scale because of its predictability and intensity [3]. These advantages have given it the priority to be selected and developed in Malaysia as a new energy source as proven in Ariff [4].

Marine current turbines can be classified according to the orientation of the rotating axis. A horizontal axis marine current turbine (HAMCT) is an axial flow rotor which is favoured generally for wind turbines. The cross flow rotor or vertical axis marine current turbines (VAMCT) are either of drag or lift designs. Another alternative, the reciprocating device has also been developed. Nevertheless, in previous work done by Firdaus [5], the power coefficient of HAMCT is greater than the others, which means the HAMCT offers a great potential in power generation. Hence, this project mainly focuses on developing a rotor of horizontal axis marine current turbine (HAMCT) owing to Malaysian ocean characteristics.

1.2 Problems Statement

The horizontal axis turbine is very much depending on marine current speed and water depth. From the prototypes that have been developed and tested by other countries, the ideal marine current speed to make the turbine work is at least 2 m/s (4 knots). However, the averagely marine current in Malaysia is only 1 m/s (2.0 knots) [4], which is half of the speeds for which turbines have been developed in other countries. To develop a turbine in a low current speed, a big system of turbine is needed. The problem, however, lies in the blade diameter, which is limited to water depth. Therefore, some modification must be made on the current speed or the turbine itself, or both to enable the turbine to work in low current speed.

There are two approaches to improve the above mentioned problems. First approach is to modify the rotor parameters such as its diameter, number of blades, blade shape etc. The other method is to increase the water flow by placing the rotor in a duct, since Brian [6] in his comparison work had proven that by placing the turbine in the duct, the output power of the turbine will be increased by about three times than an open turbine of similar swept area.

1.3 Objective

The objective of this project is to develop a ducted horizontal axis marine current turbine (HAMCT) rotor to extract marine current energy suitable for Malaysian seas.

1.4 Scope of project

The scope of the project consists of the following:

1. Performing literature review on marine current energy resources, prototypes of HAMCT that have been developed by other researchers, duct principle, and rotor blade aerodynamic design.
2. Determination of a suitable shape of duct to place the rotor, developing ducts using Computational Aided Design (CAD) software and analysing the designs using Computational Fluid Dynamic (CFD) software.
3. Determination of rotor parameters those are suitable to be placed in Malaysian water, and developing rotors using CAD software.
4. Analysing developed rotors using CFD software in two different conditions; ‘without duct’ condition, and ‘with duct’ condition and calculating their performance.
5. Calculation of rotor performance using Blade Element Momentum (BEM) theory.
6. Comparison of the rotor performance between CFD simulation and BEM theory.
7. Validation of the results by comparing the results with previous work that have done by other researcher.