© (2015) Trans Tech Publications, Switzerland
doi:10.4028/www.scientific.net/AMM.772.556

Design of a Gorlov Turbine for Marine Current Energy Extraction

Niranjwan Chettiar[1, a], Sumesh Narayan[2, b], Jai Nendran Goundar[2, c] and Ashneel Deo[2, d]

[1] Department of Properties and Facilities, The University of the South Pacific
Laucala Campus, Suva, Fiji.

[2] Section of Mechanical Engineering, The University of the South Pacific
Laucala Campus, Suva, Fiji.

[a]chettiar_n@usp.ac.fj, [b]narayan_su@usp.ac.fj, [c]jai.goundar_j@usp.ac.fj, [d]deo_a@usp.ac.fj

Keywords: Renewable Energy, Marine current Energy, Gorlov Turbine, Design, Experimentation.

Abstract. As fossil fuels near depletion and their detrimental side effects become prominent on ecosystems, the world searches renewable sources of energy. Marine current energy is an emerging and promising renewable energy resource. Marine current energy can be alternative energy source for electricity production. Many marine current converters are designed to tap marine current energy; however, Gorlov turbine proves to have minimum manufacturing and maintenance cost, hence giving desired power output. A 0.3m diameter and 0.6m long 3 bladed Gorlov turbine was designed, fabricated and test to analyse its performance. The turbine produces average power 15 W and proves to be quite efficient for marine current energy extraction.

Introduction

Energy extraction with marine current turbines promises to be an environmentally friendly way to generate renewable electric energy with no emission of green house gases during normal operation. Technology development in this field is on-going. This process utilises kinetic energy flowing in tidal current channels as well as river streams and man-made waterways for electricity generation [1].
Marine current energy converters can be categorized into three main types, namely horizontal axis, vertical axis and cross flow turbines. Since the density of the seawater is 832 times denser than air, it has inspired various scientists to implement wind energy conversion mechanism in the oceans [2,3]. The earliest tidal current turbine in China was developed and tested in 1970s [4]. The prototype with a ship propeller type turbine adopted hydraulic system for power transmission and generated 5.8 kW at the current velocity of 3m/s.

Vertical axis designs are attractive because they respond to flow from any direction, and allow the generating equipment to be located clear of the water, driven by the vertical shaft. One of the best-known examples of a vertical axis tidal turbine is the Darrieus turbine, which has three or four thin, straight blades with hydrofoil cross-section mounted vertically at the end of radial arms. Some stand-alone prototypes have been tested under laboratory conditions by Takamatsu and Takenouchi [5, 6]. Gorlov introduced a patent of his own in which the blades are designed with a helical twist relative to the axis of rotation [7]. Helical blade turbines have quite a small rate of pulsation, and its starting characteristic was more favourable than other vertical axis turbines with straight blades [8].

The dynamics of a turbine is very important aspect of power generation from the ocean currents. It is through the blades that the energy of the ocean is converted to mechanical energy that in turn rotates the shaft of the turbine. The blade shape and utilising the principles appropriately would lead to effective work done by the blade.

Selection of Hydrofoil

National Advisory Committee for Aeronautics (NACA) profiles were considered as Hydrofoils since its proven scientific analysis in wind energy and marine current energy. Hydrodynamic characteristics such as pressure distribution on the airfoil surface, the minimum coefficient of pressure (C_p), coefficient of lift (C_l), coefficient of drag (C_d), and lift to drag ratio (L/D) must be considered for hydrofoil selection. NACA00XX series airfoils were studied from which two best airfoils has been selected to analyse its performance based on the torque generation. The hydrofoils were tested through computational fluid dynamic simulation. The inlet velocity was kept constant at 1.2m/s, while the blade speed was kept as variable speed. The graph shown in Fig. 1 shows the torque comparison between NACA0015 and NACA0024.

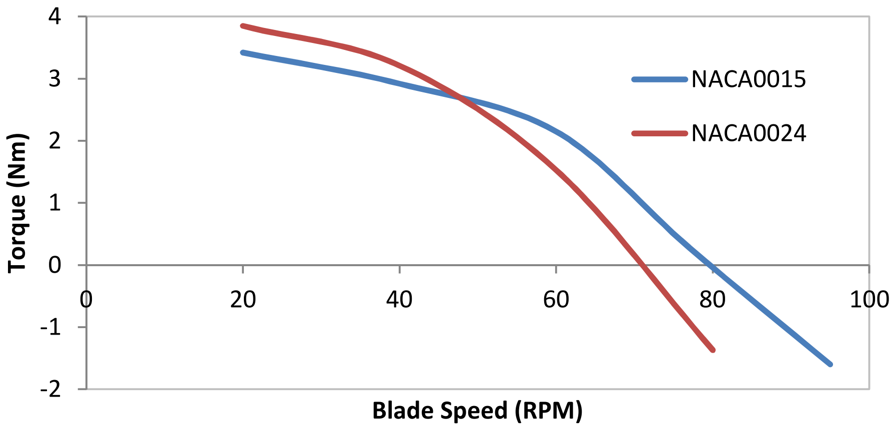

Fig. 1: Torque comparison with two different blade profiles

The symmetrical shape enables a bi-directional movement of the blade, which is very essential in the ocean to extract maximum amount of power available with emptying and filling of the ocean basins by the tide. The thickness of the profile enhances the forces acting on the blade, this due to the increase in the pressure difference being created between the lower and upper surface of the blade. NACA0024 is more suitable for lower tip speed ratios (TSR) while NACA0015 is better with slightly higher TSR.

The performance of the turbine was considered at different solidity ratios as part of the analysis; three different solidity ratio geometries were considered ranging from 0.25 to 0.35 and were analysed at four different TSR. The optimum solidity ratio proved to be 0.3.

Turbine Design

A helical marine current turbine was designed using a blade profile of NACA0015, with diameter of 0.3m and 0.6m length. The blade profile had chord length of 100mm resulting to a solidity ratio of 0.32. The helical blades make 120 degree rotation along its vertical axis.

The model constructed in AutoCAD was imported into meshing tool ANSYS – ICEM CFD. Hexahedral grid were generated to obtain higher accuracy with very fine meshing was done close to the hydrofoil, for more accurate results. The global axis was setup and the respective regions for rotating and stationary zones were created. Additional regions were created to apply smooth meshing, as the type and size of the elements play a vital role in the solution of the analysis. Far field boundary was created to stipulate reality behaviour of the blades in the ocean. The field was far enough so that it does not influence the result by restricting the boundary. A ring like domain is created to make a rotating movement of the blades, while rest of the domain remains stationary. The interfaces enable the sliding mesh as a boundary condition.

Computational Fluid Dynamic Analysis

CFD analysis was carried out to analyse the Gorlov turbine to compare with experimental results. Boundary conditions are necessary to specify the flow and thermal variables on the boundaries of the physical model. Inlet velocity condition is used to define the velocity properties of the flow at inlet boundary of the model which is set at 1.2m/s and setting the flow in X direction. The inlet speed is varied accordingly for different simulations. The back flow principle is applied as pressure outlet condition. Wall Conditions are used to restrict the fluid and solid regions. The far-field boundary and the 3 blades are set as stationary wall, while the face connecting with blades on the side is given a rotating wall. Fluid zone is kept as water, where all active cell equations are solved. The model is divided into two fluid zones; one is rotating while the other is stationary. The face between the rotating fluid zone and stationary fluid zone is specified as interface, while rest of the interface of the cylinders is specified as interiors. A time-accurate sliding mesh method is useful for modeling multiple stages in turbo-machinery applications. The Solver is taken as Pressure based with implicit formulation.

After all parameters were set the solution is initialised, with respect to the inlet velocity. Convergence criteria are set up with all parameter having a residual of 0.001. The blade torque was monitored, until iteration converged as shown in Fig. 2.

Through repetitive iterations and rotations of the blades during simulation determined that after 3 revolutions the results become steady shown in Fig 2.

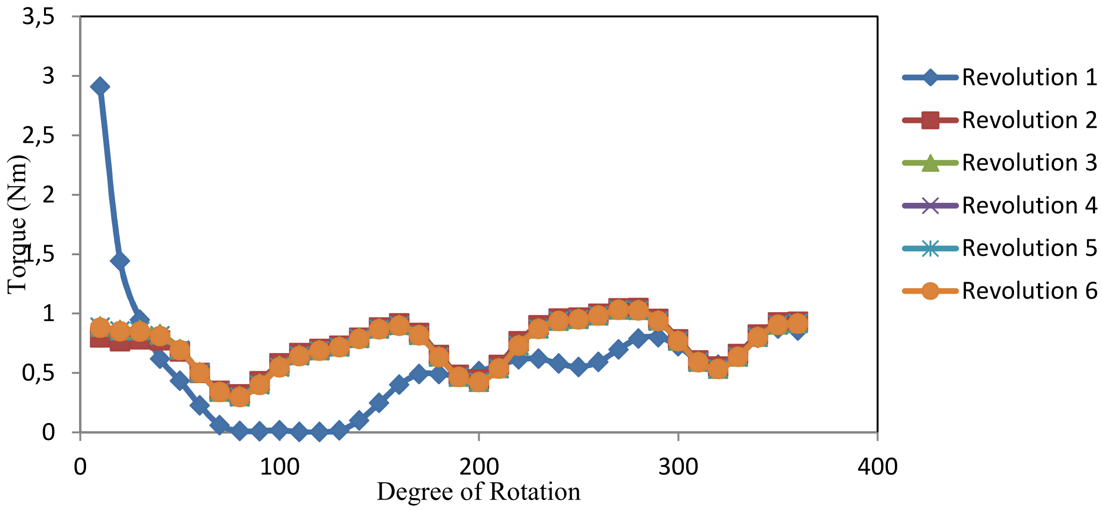

Fig. 2: Simulating the helical blade for six revolutions to obtain steady results

It was verified that the greater the mesh elements, the accuracy of the results increases. The mesh elements were varied from 1 million to 4.9 million, which resulted in an increase in Power from 4.3W to 15.7W for the model simulated.

The Fig. 3 below explains the Bernoulli's principle, when the blade is making the first half of the rotation, the velocity is reduced dramatically, and thus the pressure on the upper surface increases, and whereas the velocity at the lower surface is high with lower pressure. This pressure difference creates a net hydrodynamic force; one is acting upwards as lift force while the other acts along the flow stream, known as drag force, which is similar to the aerodynamic forces.

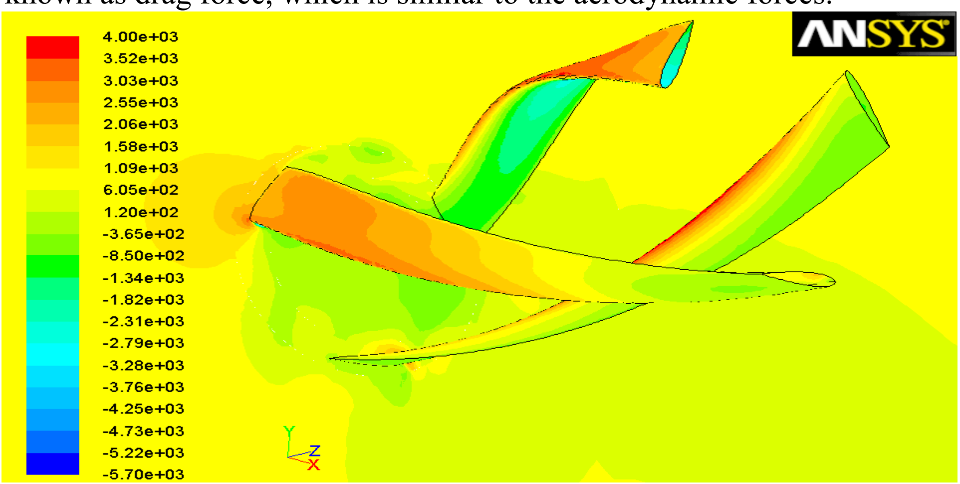

Fig. 3: Pressure contour on the helical blades at 70 degrees having a free stream velocity of 1.2m/s and blade speed of 60rpm

Validation of CFD with Experimental Results

The experiment was carried out in a towing tank facility [9]. The towing tank has electronic speed controls which were varied to test the turbine at different free stream speeds. Load cells were used to measure the forces, from which the torque was calculated, while a magnetic pick-up was used to measure the rotational speed of the blades in revolutions per minute.

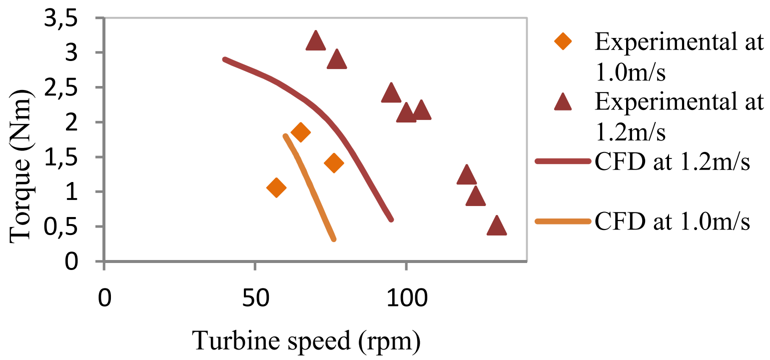

Fig. 4: Graph showing the comparison of experimental and CFD torque values at different free stream velocity and blade speeds

Fig. 5: Gorlov experiment model

CFD analysis has predicted torque close to the experimental values, though there is a slight shift in Fig. 5 but it follows the same trend as the experimental. CFD results have slightly under predicted the torque, since the CFD geometry did not have an axial shaft and frame as shown in Fig. 4. The wakes formed around the turbine frame increased the tangential acceleration on the blades. This clearly evidenced in a velocity of 1.2m/s.

Summary

The analysis part was carried out in FLUENT to get the various forces and torque of the blades. The helical turbine with 4.9 million mesh elements was analysed at different free stream speeds and blade rotational speeds, in order to validate with the experimental results. The experiment had 3 Nm at 60 rpm whereas the CFD predicted 2.5 Nm. CFD predicted maximum torque of 2.9 Nm at 40 rpm. The CFD results were close to the experimental results, which would reduce the cost of constructing working models frequently. CFD tests could be carried out before a suitable model is fabricated. Since most CFD values are under predicted, thus the expectations from a working model could be slightly higher.

The Helical motion of the blade creates an effect of forces to be evenly distributed at the foil sections along the axis of rotation throughout the rotation cycle, so there is always a foil section at every possible angle of attack. In this way, the sum of the lift and drag forces on each blade do not change abruptly with rotation angle. The turbine generates a smoother torque curve, so there is much less vibration in comparison to Darrieus design. It also minimizes peak stresses in the structure and materials, and facilitates self-starting of the turbine. It is also more marine organism friendly compared to Darrieus turbine.

References

[1] A.M. Gorlov: Tidal Energy, Vol 32, p.2955-2960 (2001).

[2] C.A. Douglas, G.P. Harrison, and J.P. Chick: Life cycle assessment of the Seagen marine current turbine, Journal of Engineering for the Maritime Environment, Vol 222, p.1–12 (2008).

[3] Fraenkel PL. (2007) 'Marine current turbines: pioneering the development of marine kinetic energy converters', Journal of Power and Energy, Vol 221, pp.159-169.

[4] H.W. Liu, S. Ma, W. Li, H.G Gu, Y.G. Lin and X.J. Sun: A review on the development of tidal current energy in China, Renewable and Sustainable Energy Reviews 2011, Vol 15, p.1141–1146 (2011). [5] Y. Takamatsu: Experimental studies on a preferable blade profile of Darrieus type cross-flow water turbine, JSME International Journal, Vol 34, p.149-156 (1991).

[5] Y. Takamatsu: Experimental studies on a preferable blade profile of Darrieus type cross-flow water turbine, JSME International Journal, Vol 34, p.149-156 (1991).

[6] K. Takenouchi and A. Furukawa: Self-starting characteristics of ducted Darrieus turbine for extra-low head power, In: Proc. of Expo World Conf. on Wind Energy, Renewable Energy, Fuel Cell & Exhibition, Hamamatsu, Japan, p.1-4 (2005).

[7] A.M. Gorlov: Waving in energy, International Water Power and Dam Construction, Vol 55, p.26-29 (2003).

[8] M. Shiono, K. Suzuki and S. Kiho: Output characteristics of Darrieus water turbine with helical blades for tidal current generation, Proceedings of the Twelfth International Offshore and Polar Engineering Conference, Kitakyushu, Japan, p.859-864 (2002).

[9] Y.M. Dai, N. Gardiner, and W. Lam: CFD modeling strategy of a straight-bladed vertical axis marine current turbine, Production of the International Offshore and Polar Engineering Conference, Vol 1, p.767-773(2010).