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Design and Testing of a Tidal Current Power Extraction Device

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ABSTRACT

The pace of the development of devices that can harness the energy of tidal currents from the ocean and convert that energy into electric power has been increasing rapidly in recent years. Groups such as the Supergen Marine Energy Consortium in the UK have begun the fundamental research in this field and have contributed to the successful deployment of tidal devices (in the case of Supergen, off the Scottish coast). As the feasibility of tidal power is being demonstrated, the research path moves to evaluating efficient, reliable and robust tidal power devices. This project addresses fundamental gaps in research knowledge; specifically, how small can these devices be constructed for model testing, how does the model test data scale up, what do the power generation curves look like and do how they change with scale. This is the first stage of a multiphase project. A 0.46m diameter vertical axis tidal current power extraction device is designed, and will be constructed and tested at a selection of current velocities. Testing will follow in 2011. The Darrieus style blade was chosen for this project and specifications of the model turbine design are included. The next two phases of this research will be used to study two larger but geometrically similar models and to investigate scaling characteristics. Data from these tests will be available for validation of numerical models.

Keywords

Tidal, Power, Marine, Energy, Extraction

1 INTRODUCTION

This work follows on from the investigations into hydrokinetic turbines by such researchers as Alidadi (2009) and Rawlings (2008) who designed and tested a small hydrokinetic device and completed a corresponding numerical program; Batten et al (2006, 2007, 2008) at the University of Southampton who have completed considerable work on hydrokinetic devices as members of the Supergen Marine Consortium; Kahn et al (2007, 2008, 2009) at Memorial University of Newfoundland who have completed work on hydrokinetic device configuration; and Li and Calisal (2010). However, there is much fundamental work to be done to progress the tidal current power extraction field.

More examples are required to illustrate the value of physical model testing (Curran 2011). Marine propulsion and offshore research has a long history with physical modeling, and although tidal current power extraction turbines are not propellers, the work that has been done on propulsion systems offers researchers and developers many methods of investigation and solutions to some of the problems that need to be addressed such as scaling in water (Molloy 2007, Molloy et al 2004, Islam et al 2007), efficiency of blades, wave and current interaction, moorings, material properties, fouling, maintenance, and repair.

Tidal current power extraction devices have now been developed to the point where they are operational; and some have been successfully deployed for commercial use off the coast of Scotland. In Canada, demonstration devices are in the process of being deployed in the Bay of Fundy with the support of Nova Scotia Provincial Government. Many challenges are being encountered as the devices are deployed; these include broken blades (Anon 2010) and mooring issues due to excessive loads and environmental challenges such as high rates of fish killing. In order to economically investigate these and other challenges and to improve the operating efficiency of the turbines, modeling capabilities need to be robust and reliable. Using numerical modeling is the optimum solution given the breadth of configurations and environmental scenarios that can be investigated. However, there is very limited corresponding data available to validate the numerical work that is being done. A comprehensive series of model tests will be a valuable resource for comparison and validation of numerical work. Work from this project will provide a comprehensive set of publically available baseline experiments that identify scaling issues such as frictional scaling or roughness scaling that need to be considered when using physical and numerical models to develop newer turbine systems. It is also not clear how the power curves of these devices look. Completion of testing of a series of scaled devices will give researchers and developers a comprehensive picture of the powering expectations from tidal devices.

Batten and the sustainable energy research group from the University of Southampton (2006, 2007) (Bahaja et al 2007, 2008) have used experimental methods (both in a tow tank and in a cavitation tunnel) and numerical methods to explore the hydrodynamic performance of horizontal axis marine current turbines, and have focused on the design of the blade. Kahn et al (2006, 2007, 2008, 2009) have investigated blade designs and compared horizontal and vertical axes in both tow tanks and numerical work. Li & Calisal (2010) have begun looking at multiple turbines and interaction factors. As the development of tidal current power extraction devices moves from creating devices that are operational to devices that are more efficient, there will be a pressing need to use modeling to evaluate small changes in designs. This work will help to build these modeling tools.

2 METHODOLOGY

This project addresses four fundamental questions: (1) what are appropriate sizes for these devices in model testing, (2) how do the model test data scale up, (3) what do the power generation curves look like and (4) how do these curves change with scale.

The first stage of this project is the design, construction and basic testing of the tidal device.

A vertical axis was chosen based on the work of Dr. Barry Davis from National Research Council Canada, Rawlings (2008) and Kahn et al (2009, 2009a, 2009b). Vertical axis turbines rotate in the same direction, can generate power when the water is flowing in either direction (ebb or flow tides), and have a straightforward configuration that is valuable for a series with different scales. A free stream configuration was chosen over a ducted model. Ducts will be investigated in the future. The following are the experimental factors that are being investigated over the time of the project.

- Power coefficient
- Variability in torque at different blade orientations
- Drag forces on blades
- Effects of shafting system on overall performance
- Blocking effects

In order to maximize the data available, the design of this turbine was based on the design of the turbine examined by Alidadi (2009).

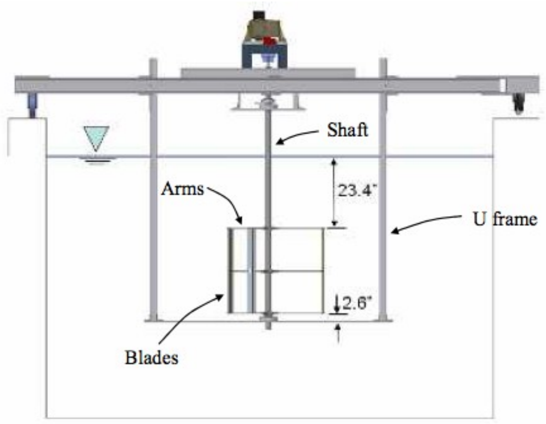

Figure 1: Turbine Assembly (Alidadi 2009)

2.1 Design of Tidal Power Extraction Device

The first stage of this project will be focused on a smaller model than Alidadi's in order to enable it to be tested at a number of facilities available to the researchers, see Table 1.

Table 1: Model Turbine Dimensions

Parameter	Dimension
Turbine diameter	0.4575m
Number of Blades	3
Blade Span	0.3429m
Blade Profile	NACA 634-02 1 and 634-42 1
Chord Length	0.034m in ideal; 0.0325m in manufactured
Shaft outer diameter	0.024m

Investigating the consistency of tidal device model testing results across facilities is part of the mandate of the ECOR Marine Renewable Energy Specialist Panel mandate for 2010-2011. This panel will facilitate testing through different facilities. The data from the Alidadi (2009) and Rawlings (2008) experimental series form the data set for the second scale (Figure 2), and two larger scales will be tested subsequent to the small-scale tests.

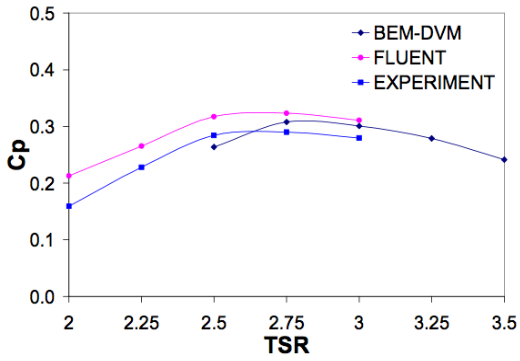

Figure 2: Results of Cp vs. Tip Speed Ratio for Unducted Turbine at U_{∞}=1.5m/s (Alidadi 2009)

The numerical method is two-dimensional and is based on potential flow theory. Each blade is represented with a vortex filament. The vortex shedding from the blades is modeled by discrete vortices shed from the blades as shown in Figure 3.

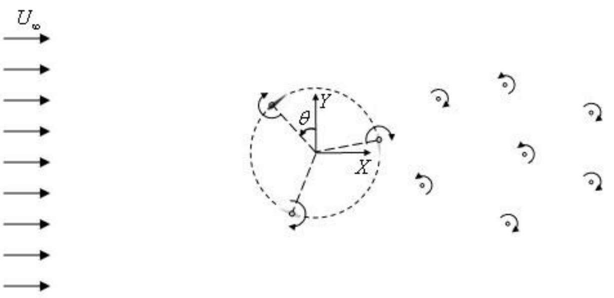

Figure 3: Discrete Vortex Modelling

Results from the numerical method will be compared to experimental results as in Figure 2. Values such as torque and shaft speed will be compared directly. The numerical torque curve is obtained from summation of torque on blades, assuming the angular velocity remains constant. The numerical results so far have confirmed that the method is able to produce compatible results with the experiments when the blades are not stalled (Alidadi & Calisal 2011).

3.3 Experimental Method

The tests will be run in towing tanks in Canada and Australia at a selection of velocities around 2m/s. The angle of attack of the 3 blades will be varied along with the tip speed ratio.

3.4 Reynolds Scaling

The average speed of the open water in which tidal turbines operate is approximately 2m/s (Johnson 2006). This provides the opportunity to scale model results without scaling water velocity. The maximum Reynolds number of the tests will be low and is expected to be in the transition region. Higher Reynolds numbers are expected at large scales and the gradual scaling in the series will inform the scaling procedure developed out of this work.

3.5 Power Generation

The Betz-limited maximum power generation from the 0.34 m blade span turbine in 2 m/s flow is 430 watts, with power increasing for larger devices as the square of the blade span diameter. As indicated in Figure 2, actual turbine efficiencies may be half of the Betz limit (0.3 or less rather than 0.59), with corresponding mechanical power generation for the 0.34 m turbine on the order of 200 watts. Power generation will be evaluated as a function of tip speed ratio, angle of attack, and scale.

4 SUMMARY

A large project has begun that will be focused on investigating modeling, scaling and power characteristics of tidal power extraction devices. Testing of a geometrically similar set of model vertical axis tidal devices will be used to develop a comprehensive set of powering curves, provide data for numerical modeling and investigate consistency of data acquisition across a selection of towing tanks of different dimensions. Alidadi (2009) has completed a comparison of experimental and numerical test results of a mid-scale model in this series. Testing on the smallest scale model is beginning and will be underway 2011.

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