Design and Structural Testing of Blades for a 2MW Floating Tidal Energy Conversion Device

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Abstract. The floating tidal energy is increasingly recognised to have the potential of delivering a step-change cost reduction to the tidal energy sector, by extracting energy from deeper water sites through energy conversion devices. To ensure the normal operation of a tidal energy convertor within its service life, the device should be designed properly and evaluated through a series of strength and durability testing. The Large Structures Research Group at NUI Galway is working closely with, renewable energy company, Orbital Marine Power and, blade manufacture, ÉireComposites Teo, to design and test the next generation of SR2000 tidal turbine blade, with aims to increase the turbine power production rate and to refine the design for low cost. This paper presents a brief description of the structural design and testing of a blade for the O2-2000 tidal turbine, one of the largest tidal turbines in the world. NUI Galway will utilise their in-house software, BladeComp, to find a blade laminates design that balances both blade strength and material cost. The structural performance of the designed blade will be assessed by conducting static and fatigue testing. To achieve this objective, a support frame to fix the blade is designed, a load application device is introduced and the methodology for design tidal loading conversion is proposed in order to complete the testing at NUI Galway.

Introduction

After many years of delay, tidal stream energy is now becoming a commercial reality. The MeyGen project is set to become the first 4-turbine, 6MW tidal array [1]. At the same time, EDF is committed to projects in France using the OpenHydro/DCNS tidal device and projects are also being considered in the Bay of Fundy in Canada and elsewhere [2]. A number of market assessments for tidal stream energy have been independently developed and, as with any early-stage technology sector, there is a wide degree of variation between projections. The International Energy Agency's 'Blue Map' [3] medium growth scenario predicts 13GW of installed tidal capacity by 2050, with a high growth scenario of 52GW over the same period.

Despite the huge growth potential in the tidal energy market, there is only limited data available about how composite materials will perform under high cyclic loading in harsh marine conditions. Moreover, there is no published work available for the full-scale fatigue testing of tidal blades. Therefore, the Large Structures Research Group, NUI Galway is collaborating with Orbital Marine Power (OMP) Limited in the H2020 FloTEC and the OCEANERA-COFUND SEABLADE projects to design and test a full-scale blade for the OMP tidal turbines.

The Large Structures Research Group at NUI Galway has many years of experience in structural design and processing of glass and carbon fibre-reinforced composite materials. As a member of the MaREI Centre, the group has developed advanced computational design methodologies [4,5] for tidal current turbine blades, performed design and optimization studies on wind turbine blade structures of several scales [6]-[8], and conducted structural testing of components for a 3/8th scale blade and rotor subsection for the OpenHydro prototype tidal turbine [9].

Orbital Marine Power (OMP) Limited is credited with pioneering floating tidal stream turbines since the company's formation in 2002 in Orkney, Scotland. OMP has maintained and advanced this position by developing the world's leading engineering knowledge and technology in floating tidal stream turbines. The OMP SR2000 produced unrivalled performance during a demonstration programme, where it delivered multiple world-firsts, including exporting over 3,250 MWh of electricity to the Orkney grid during a 12 month period. This was more than the entire wave and tidal sector in Scotland had exported over the 12 years prior to the launch of the SR2000.

In this paper, the two aspects detailed are the structural design and testing of the O2-2000 turbine blade, which is the next generation of the SR2000 blade. The NUI Galway in-house developed software BladeComp is utilised to design and optimise the layups of the O2-2000 blade in order to balance both blade strength and manufacturing costs. The structural testing aims to evaluate the blade performance under both extreme static loading and long-term fatigue loading, which will be conducted in the Large Structures Research Laboratory of NUI Galway.

Blade Design

The turbine blade targeted in this research is designed for the OMP floating tidal energy converter (Fig. 1). It has a capacity of 2 MW and is equipped with two 20 m diameter twin-bladed rotors, which make it one of the largest tidal turbine systems in the world. The aerodynamic design, which addressed the external shape of the O2-2000 blade (Fig. 2), was conducted by OMP. The structural design of the blade has been generated and assessed using BladeComp, which automates the process of generating, analysing and post-processing finite element analysis models of tidal turbine blades. This software acts as a wrapper for the finite-element (FE) software, utilising the advanced mechanic features of the FE technics and tailoring the analysis to specifically address the design of tidal turbine blades based on genetic algorithm.

The designed O2-2000 turbine blade consists of a single internal shear web. The blade trailing edge fairings and the blade tip are constructed separately to the main body and will be adhesively bonded to the finished structure. The O2-2000 turbine blades are constructed from glass-fibre epoxy, using a "semi-preg" powder epoxy material technology developed by project partners ÉireComposites Teo. The laminates that comprise the turbine elements are reinforced with unidirectional and biaxial E-glass plies. The biaxial plies are used in the leading and trailing edge sections of the blade shells and the shear webs. The blade sections subjected to bending stress (the spar caps and root region) will include significant unidirectional reinforcement. The flapwise and edgewise design loading profiles defined for the blade design and structural testing were supplied by OMP.

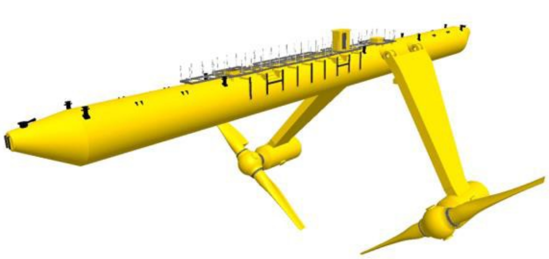


Fig. 1 The Orbital Marine Power Ltd designed floating tidal energy convertor

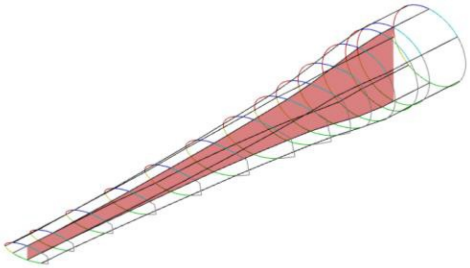


Fig. 2 The Orbital O2-2000 tidal turbine blade

Structural Testing

With the O2-2000 tidal turbine blade designed and manufactured, the structural testing, which includes both static and fatigue mechanical tests, will be conducted in the Large Structures Research Laboratory located in NUI Galway. Fig. 3 shows the test setup overview. The blade is supported at its root on the support frame and will be loaded via three hydraulic actuators ranging in capacities from 240 kN to 750 kN. The actuators can be controlled separately, and thus will enable the application of complex loading patterns in the static and fatigue testing. The load amplitudes of the actuators are converted from the design loading profiles to simulate the operating conditions of the blade underwater.

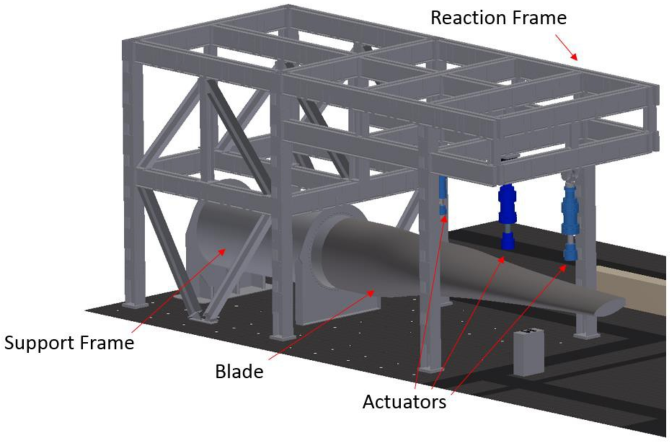


Fig. 3 Overview of the test setup

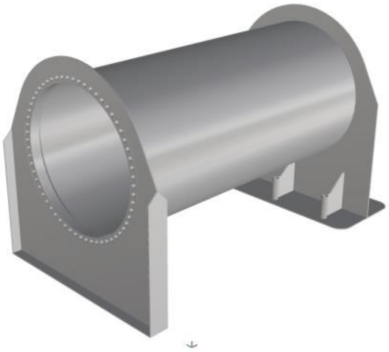


Fig. 4 The support frame

Support Frame. During the testing, the blade root is expected to be fully constrained. To achieve this, a root support frame was designed, which is shown in Fig. 4, where there is a ring of bolt holes drilled on the front surface of the support frame, with a pitch hole diameter of 1640 mm. However, the pitch hole diameter of the O2-2000 blade root is 1400 mm. Thus, an adopter plate, with two rings of bolt holes drilled on its surface, is designed to mount the blade root on the support frame. To prevent the blade root movements during the static and fatigue testing, the support frame is connected to the reinforced concrete reaction floor of the laboratory through pre-tensioned bolts.

Load Application. Three hydraulic actuators will be used in the static and fatigue testing for load application purpose. Swivel connections are used to mount the actuators to the reaction frame. Thus, no moments will be introduced to the blade. During operation, the whole blade external surface will suffer tidal loads. Thus, more load points will result in better simulation of blade operation conditions. Since there are only three actuators available, a load introduction device is designed to introduce more point loads. As shown in Fig. 5, the triangle-shaped device can transfer a single load from actuator to two bottom contact surfaces. By employing this device, the load point number is doubled, which allows a good simulation of tidal loads. To spread the point loads uniformly to the blade surface and avoid the local damage, a clamp device is used, which is shown in Fig. 6 and is a steel section filled with plywood or Nylon. The clamp comprises of two parts, a pressure side and a suction side. The inner surface is in contact with the blade external surface. A 5 mm thick rubber layer will be padded on the blade surface to avoid any damages. The clamp allows for testing the blade both in the pressure-to-suction and suction-to-pressure directions without any change in the test set-up, which is capable of both static and fatigue testing.

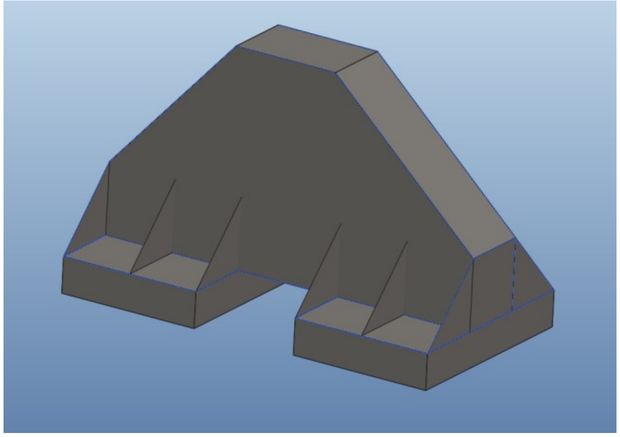


Fig. 5 The load introduction device

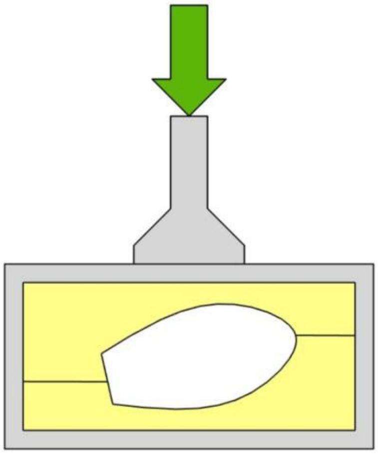


Fig. 6 The clamp for load introduction

Data Acquisition. The strain values on the blade surface will be measured by the electrical resistance strain gauges to monitor the damage occurrence of the composite materials. Two types of displacement transducers, namely the draw-wire string potentiometers and the LVDTs, will be employed to measure the deflection of the blade and the root movements of the blade root connection. Additionally, a Digital Image Correlation (DIC) and a laser scanner will be utilised to supply more detailed information about the blade deformation. The blade natural frequencies will be measured by a laser vibrometer to estimate the blade damage level under fatigue loading.

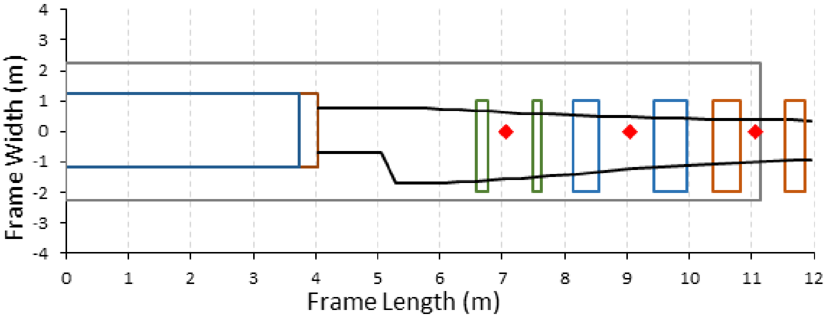
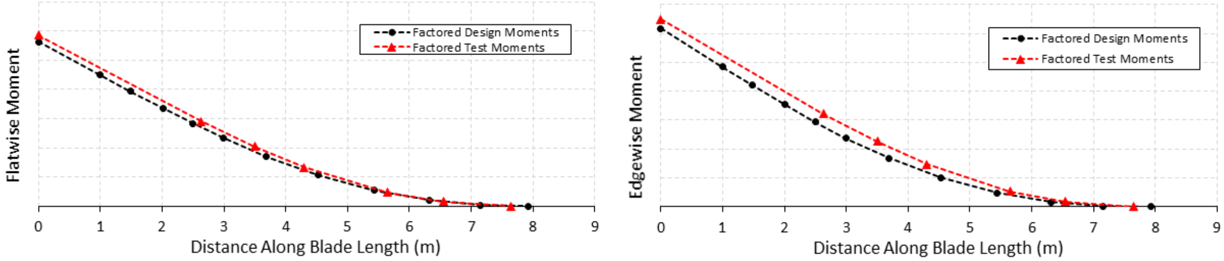


Fig. 7 The load application locations of the blade

Test Loading Definition. The tidal loads can be decomposed into flapwise and edgewise components. In the static testing, to simulate the extreme loading condition of the tidal turbine, the loads in two directions should be applied to the blade simultaneously. But due to the facility limitation, there are only three actuators available in the laboratory which only allows for applying flapwise loads. To overcome this issue, the blade will be installed with a specific pitch angle. By pitching the blade, an attack angle is introduced to the actuator load direction, which will introduce additional edgewise loading to the blade. It should be noted that the load point locations (Fig. 7) cannot be adjusted as the actuators are fixed. Thus, only the blade pitch angle and the actuator amplitudes can be tuned to make the blade load profiles (including moments and shear loads) under testing loading agree well with that under design loading. For this purpose, a genetic algorithm based calibration was conducted. The variables to address in the calibration are the blade pitch angle and the actuator load amplitudes. The goodness-of-fit is judged according to the mean error between the blade moment and shear profiles under the design and calibrated loading. The calibration results show that the optimised blade pitch angle should be 12.5°. The blade moment profiles under the design loading and the calibrated test loading are compared in Fig. 8. Good agreement can be found in these comparisons, which indicates that the method of pitching blade to get the flapwise and edgewise loads applied simultaneously is suitable for the static testing.

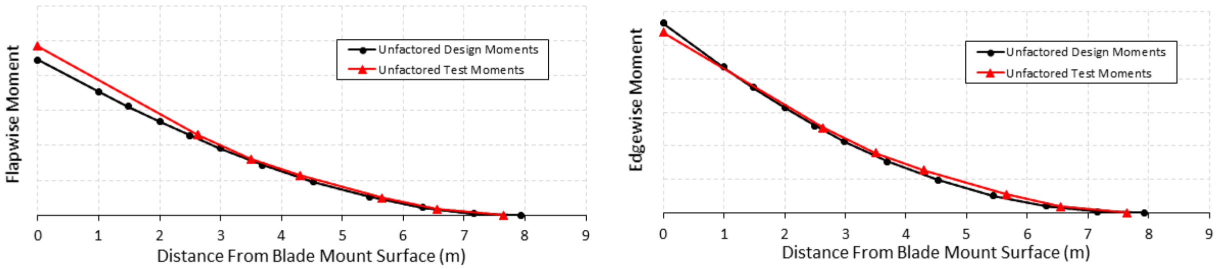


(a) Flapwise moments *(b) Edgewise moments*

Fig. 8 Design loads and converted testing loads for the static test

Regarding the fatigue testing, the damage equivalent load case defined in the Blade Data Pack [10] is used. Similar to the static testing, calibration was conducted to obtain the blade pitch angle and actuator amplitudes. It was found that the best blade pitch angle for applying static loading is 15°. However, it is estimated that at least two weeks of additional time would be required to remove the instrumentation, disconnect and reinstall the rotated blade and reinstall the instrumentation. Thus, decision was made that the blade pitch angle used in fatigue testing keeps the same as that of static testing to reduce the testing period. Fig. 9 shows the blade load profile comparisons under design fatigue loading and calibrated fatigue loading. It could be found that the blade load profiles under calibrated fatigue loading agree well with that under design fatigue loading, without changing the blade pitch angle.

The maximum operating frequency of the actuator is dependent on its displacement amplitude. In fatigue testing, all three actuators will be adjusted to operate under the same frequency. The initial estimates for allowable actuator displacements of ±39 mm, ±18 mm and ±6 mm for actuators 3, 2 and 1, respectively. This will result in a loading frequency of 0.33 Hz, which leads to a test duration of approximately 35 days (of continuous operation) for 1,000,000 cycles. It should be noted that with consideration of stoppages for regular inspections of blade and test setup, the testing period is scheduled for approximately 2 months.



(a) Flapwise moments *(b) Edgewise moments*

Fig. 9 Design loads and converted testing loads for the fatigue test

Summary and Future Work

This paper focuses on the design and testing of a blade for a 2MW floating tidal energy convertor which is developed by OMP. The design of the tidal blade is briefed with considerations of reducing the material costs and increasing the blade strength. The preparation of the blade static and fatigue testing is illustrated, including the support frame, the load introduction mechanism and the test loading definition. Currently, the designed tidal turbine blade is being manufactured. Based on the test specifications described in this paper, the strength and durability of the blade will be evaluated through the static and fatigue testing, respectively. The test results will not only provide valuable data to gain the confidence of OMP in the commercialisation of the O2-2000 tidal turbine but also contribute to the field of full-scale testing of tidal turbine blade.

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