

# Ensuring Reliability for Marine Renewable Drive Train Systems – Nautilus Testing Facilities

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## Abstract

**For marine renewable energy to be de-risked and be seen as an attractive investment, wave and tidal stream energy extraction technologies need to be rigorously tested and certified. New large facilities and infrastructure will be required to perform this advanced testing. In response to this Narec is building the world's first drive-train test facility dedicated to the requirements of the marine renewable's sector. The €15.4m Nautilus Test Facility will provide a 3MW drive system capable of testing the complete drive train, electrical generation, control and support systems of marine renewable devices. The Nautilus rig will allow the key components and assemblies (including drive shafts, bearings, gearbox, generator and power converters), to be thoroughly tested before deployment in the open sea. The test rig will have the ability to mechanically and electrically load the complete drive train with the full envelope of load cases, including side loads on to shafts and bearings and grid faults to the electrical systems.**

**Keywords:** Nautilus, Test Rig, Tidal Stream, Risk Mitigation

## 1. Introduction

The difficulties in installing and operating wind turbines offshore are readily apparent from both the delays that can arise in initial installations and the challenges of implementing repairs to large components such as bearings, gearboxes and blades [1]. These problems are driven by variable weather, extreme load cases and demanding marine

environments. In contrast to the wind sector that has been developing over an extend number of decades; the marine renewables sector is much less mature. Therefore the reliability issues that have dogged offshore wind are at least equally important to marine renewables because access for remedial work offshore cannot be guaranteed, meaning that devices may be off-line for longer periods. The overall emphasis must therefore be on improving the reliability of systems prior to offshore deployment.

In recognition of this the UK government has commissioned Narec to develop Project Nautilus. This is a multi-mega watt rotary test rig capable of testing tidal stream Drive Train systems at full scale and in a representative manner. Testing will be conducted in order to evaluate performance and optimise reliability prior to actual sea deployment.

## 2. Market Review

At the outset of this project a market study was undertaken to determine the optimal nature of the test rig. This exercise was made with clear reference to the market and its technology development companies. A process of sector engagement was undertaken via web searches, questionnaires, telecoms and face to face meetings. The results of this process were consolidated such that in conjunction with estimates of the market trends and practical limitations of time and money, specifications for the rig were derived. Whilst within the tidal stream sector there is some evidence of technology consolidation, clear configuration differences are apparent amongst those developers implementing Direct Drive electrical generators and those opting to use a gear box. As highlighted by the market study output this represents a significant design challenge in the development of the rig.

### 3. Outline Description of Rig

The Nautilus Test Rig shown in Fig 1 consists of a number of major subsystems. A motor rated to deliver 3256 kW has been procured from ABB in order to act as the prime movers in the rig. A 20:1 reduction gear box has been procured from David Brown Ltd. This develops output shaft torque and rpm characteristics that represent the ranges of those typically experienced by tidal stream drive train systems. A Force Application System (FAS) has been designed and procured from MTS. This key item of equipment may be controlled to introduce transient degrees of freedom into the shafting arrangements which are in turn transmitted into the drive train of the test piece. A cooling system is under development to ensure that generator thermal conditions are correctly represented. A drive system has been procured from ABB to recycle the electrical power developed by the Drive Train system test piece and feed this back into powering the Motor. The principle mechanical characteristics of the Nautilus Rig are listed in Table 1.

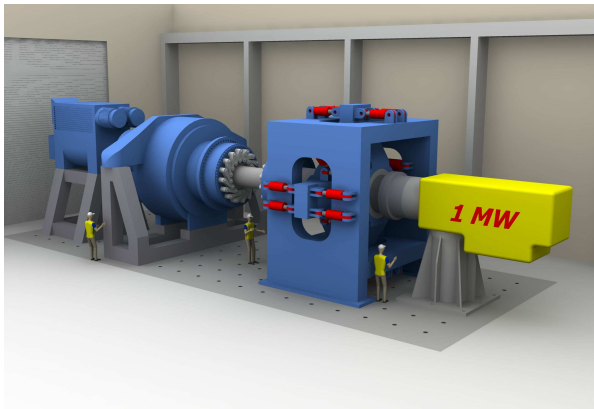


Figure 1: Nautilus Test Rig

Motor Output Speed	
Constant Power	600 rpm
Constant Torque	0 – 200 rpm
Gearbox	
Max Operational Torque	5 MNm
Max Instantaneous Torque	10 MNm
Shaft Speed at Max Torque	6 rpm
Speed Range	0 – 30 rpm
Direction of Rotation	Bi-directional
Force Application System	
Max Bending Moments	15 MNm
Max Radial loading	4 MNm
Max Axial loading	4 MNm

Table 1: Principle Characteristics of Test Rig

### 4. Force Application System

The functionality of the FAS is a key item in the Nautilus Test Rig and an aspect that differentiates it from other more conventional ‘back to back’ rotary test rigs. Analogous with the Wind Sector there are a number of operational occurrences that introduce non aligned loads and bending moments into the input shaft of a tidal stream turbine. Examples of these may include turbulence in the incident flow, yaw misaligned to the flow and more extreme events such as blade failure. More specific to the marine environment wave induced water particle accelerations will also exist.

Issues of fatigue related Drive Train component failures, induced by turbulence are of concern. Work undertaken by EMEC [2] provides an indication of wave induced and Bottom Boundary Layer (BBL) turbulence characteristics as shown in Fig 2. Additionally the wake of turbines when they are deployed in arrays or farms may also be a source of turbulence. The Nautilus FAS is designed to be able to replicate these transient forces in order that Drive Trains under test on the rig are subjected to realistic in service environmental loadings.

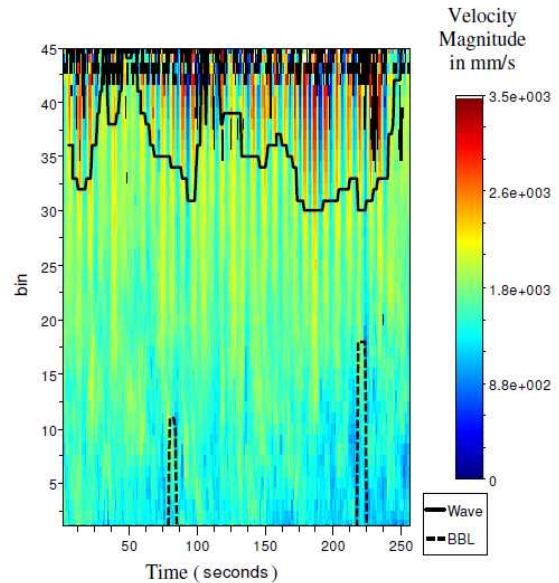


Figure 2: EMEC ADCP Data

The notation to describe the reference frame for the degrees of freedom of the system have been adopted from the Wind Sector [3] and is illustrated by Fig 3. The FAS introduces its forces and bending moments via a series of hydraulic rams that act upon a floating shaft coupling such that the rig’s drive shaft is physical displaced. The coupling is designed to not transfer these loads and bending moments back into the Nautilus gearbox and motor arrangements. A schematic of how this arrangement is achieved is shown in Fig 4.

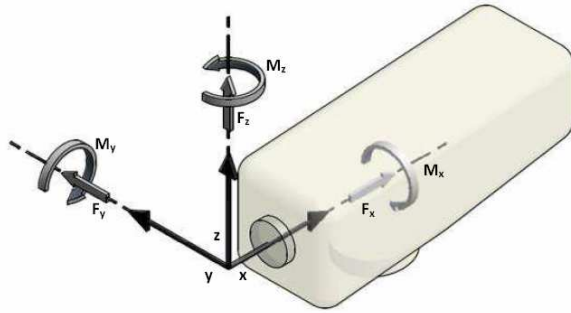


Figure 3: FAS Notation

The order of magnitude and rates of change used in the design specification of the FAS were determined using two methods. Initially a simple in-house simulation was developed using a frequency domain linearised wave theory approach which was superimposed upon a steady state tidal velocity. This was used to estimate the force acting upon a quasi static blade in terms of pressure distribution. Further analysis was carried out using Garrad Hassan's 'Tidal Bladed' software [4]. A full suite of load cases was performed using this software upon generic 1.5MW and 2MW turbine designs and correlated against the in-house simulation.

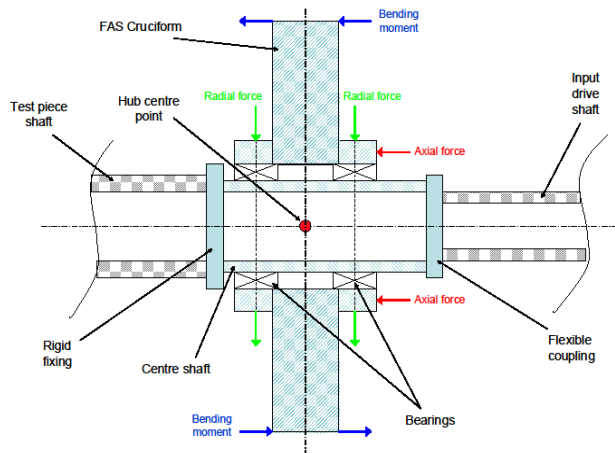


Figure 4: FAS Schematic Arrangements

## 5. FAS Control Strategy

In order to develop representative input parameters to the FAS control system, a program of research has been commenced consisting of the development of a CFD generic numerical modelling tool using a CFX platform. This model will be used to represent the spatial environmental conditions encountered at tidal turbine deployment sites and its interaction with a tidal turbine system. The development of this tool will be supported by a planned campaign of ADCP deployments in order to validate the findings of the numerical model. Also the intention is to translate data sets gained from the physical measurement of energetic

tidal stream locations (that are representative of the areas that tidal demonstration and farm), into the control parameters of the FAS. A schematic of the Nautilus control system is described by Fig 5.

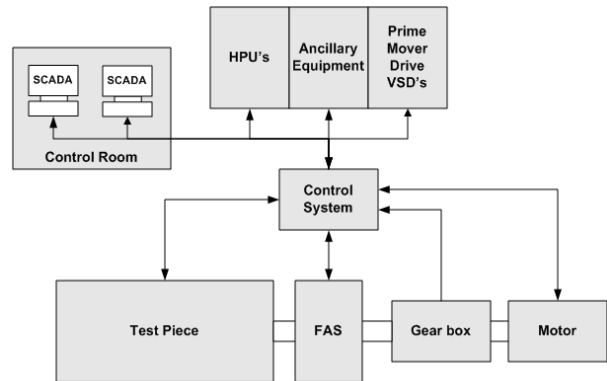


Figure 5: Control Schematic

## 6. Test Parameters

As an integrated electrical and mechanical rig, Nautilus is designed to undertake a wide range of testing. In consultation with the client using the rig it is expected that the following types of test will be typically performed;

- Overall system 'Highly Accelerated Lifetime Tests' (HALTS)
- Controlled percentage electrical overloading
- Loss of export grid power
- Emergency stops
- Mechanical fatigue loading
- Control strategies
- Wave induced forces
- Cold Starts
- Fault Current Ride Through
- Turbulence induced forces
- Thermal evaluation
- Bearing durability
- Shaft rpm run away
- Yaw and blade pitch alignment error

## 7. Conclusion

The €15.4m Nautilus test rig with its bespoke Force Application System is well positioned to allow Tidal Stream Drive Train systems to be robustly evaluated in a fully representative manner before their deployment in the open sea. The Nautilus test rig is expected to be fully operational by June 2011 and will offer the opportunity to significantly reduce the risk of the in-service failure of the key electrical and mechanical components used within tidal stream turbine technologies.

## References

- [1] Reliability of Different Wind Turbine Concepts with Relevance to Offshore Application, P J Tavner et al, European Wind Energy Conf (EWEC) 2008
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- [4] [www.garradhassan.com/en/software/GHTidalBladed.php](http://www.garradhassan.com/en/software/GHTidalBladed.php)

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