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Characterisation of current and turbulence in the FloWave Ocean Energy Research Facility

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ABSTRACT

Tidal energy is a developing industry and requires high precision test facilities which replicate the full-scale flows as accurately as possible to develop new technologies. In particular, the spatial and temporal variation must be well understood. FloWave is a state-of-the-art test facility with the ability to produce multi-directional waves and currents. This work investigates the mean and turbulent flow parameters throughout the tank using an ADV. The goal is to provide a comprehensive characterisation of the flow in the tank, in a robust and repeatable manner. These flow parameters are then compared to sample data from field measurements for context.

The turbulence intensities are normally distributed in the range of 5–11% and integral lengthscales were log-normally distributed over a 0.18–0.41 m range across the test area. The Reynolds stresses showed the streamwise-vertical pair were relatively constant throughout the depth, with values in the range −0.31 to 0.15 Pa, while the transverse-vertical pair show high vertical variation with values of −1.35 to 0.20 Pa. For the majority of locations the flow metrics are generally realistic compared with those measured at the Fall of Warness site. This work improves the understanding of flow behaviour in the tank, facilitating higher confidence testing of scaled devices.

1. Introduction

The FloWave Ocean Energy Research Facility allows the scale testing of marine energy extraction devices, with the ability to create realistic sea-states comprising combined waves and current. For tidal developers it is vital that the spatial and temporal variation of current is well characterised. This needs to consider variation with both depth and across the test area, as well as small scale temporal variation, i.e. turbulence.

The goal of this work is to present a comprehensive flow characterisation of the FloWave facility. This will allow developers to reference the flow metrics for their own tests at the facility and give context of how they compare to full-scale site conditions. Flow characterisation requires a robust methodology, taking into account instrument vibration, noise and repeatability of results. This work presents flow metrics which are used to characterise full-scale sites, assessing their variation with location and flow speed in the tank and providing distributions to quantify repeatability.

In giving context for the tank in relation to field data, it should be noted that tidal energy sites are hugely diverse and a full analysis of the drivers and range of the variations in flow metrics is out of scope for this work. However, it is important to give a basic overview of the similarities and differences to inform designers testing at the facility.

This work makes use of the newly available Nortek Vectrino Profiler, a 100 Hz sample rate pulse coherent Acoustic Doppler Velocimeter (ADV) to perform this characterisation. This work builds on previous studies (Noble et al., 2015) using Electro-Magnetic (EM) induction metres to measure the spatial variation of mean flow across the tank. It also makes use of field measurements collected at the EMEC tidal test site, made during the Reliable Data Acquisition for Tidal Platform (ReDAPT) project (Sellar and Sutherland, 2015).

Variation of flow over a range of scales is known to affect Tidal Energy Converters (TECs) (Clark et al., 2015). As testing at full scale in the sea is challenging in terms of expense and uncontrollable conditions, it is advantageous for device developers to learn as much about their design in small scale facilities, where tests are repeatable and modifications are more practical.

The authors are not aware of any published papers dealing specifically with the subject of characterisation of flow and turbulence in a wave-current basin. However, facility baseline flow conditions are

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discussed in a number of experimental studies (Park et al., 2005; Mori et al., 2007; Myers and Bahaj, 2010; Blackmore et al., 2016). The methodologies used are broadly similar to that presented here, although differ in aspects specific to the facility or measurement instruments. Flow characteristics of the Chilworth flume at Southampton were measured using a Nortek ADV (Myers and Bahaj, 2010) in order to investigate wake effects of TEC at small scale using porous disks. Results in terms of velocity defect and turbulence intensity are only presented for cases with the model installed. As part of a study investigating methods to change the level of turbulence in the IFREMER flume, flow measurements were conducted using laser Doppler velocimetry (LDV) (Blackmore et al., 2016). Velocity and turbulence metrics were calculated across a plane in the centre of the flume, forming the swept area of a model turbine being tested. Details of facility characterisation are presented in Park et al. (2005) and Mori et al. (2007), although both relate to recirculating flumes, and use LDV measurements via a window in the side of the flume, something that is not currently possible at FloWave.

2. Experimental set-up and instrumentation

2.1. The FloWave Facility

FloWave is a circular combined wave and current test tank, with wavemakers located around the entire circumference. Impellers mounted below the test area drive the current recirculation through a series of turning vanes, as shown in Fig. 1.

There is a 15 m diameter buoyant floor in the centre of the tank, which notionally represents the test area. This floor can be raised above the water level to facilitate model installation and reconfiguration as required, then submerged to the 2 m working depth. With the wavemakers powered off, the water level in the tank drops slightly, resulting in a water depth of 1.93 m, which was the configuration throughout this work. Around the circumference of the tank there are 168 active-absorbing hinged wavemakers, although they were not used in these tests.

The tank is capable of generating currents upwards of 1.6 m s^{-1}, using 28 drive units mounted in a plenum chamber below the test floor. Each of these contains a single 1.7 m diameter low-solidity 5-bladed symmetrical impeller, driven by a 48 kW motor. Turning vanes mounted below and in front of the wavemakers direct the current across the tank (Robinson et al., 2015), as shown in Fig. 1. These turning vanes incorporate porous screens to provide flow conditioning and prevent debris ingress to the plenum chamber.

Creating a horizontally uniform current in a circular tank requires precise control of the individual impellers (Robinson et al., 2014). In summary, the impeller units on either side of the required current direction on both the upstream and the downstream side of the tank are driven at varying speeds to produce the required current corresponding to the desired test velocity. Here, the highest of these impeller rotational speeds (ω) is used to reference the tank setting. The control system for the impellers includes the ability to change the direction of the current during the test. This capability allows for the simulation of cross-currents, or a tidal ellipse, without having to reposition the device model.

The tank is equipped with an instrumentation gantry from which sensors can be suspended into the flow, the base of which is 1 m above the water surface. The tank co-ordinate system is Cartesian, as shown in Fig. 2, with the origin at the centre of the tank on the test floor, and $+z$ vertically upwards. All tests were run with a current direction of 0°, i.e. flow in the $+x$ direction. Here co-ordinate sets are referred to in short as (x, y) or (x, y, z).

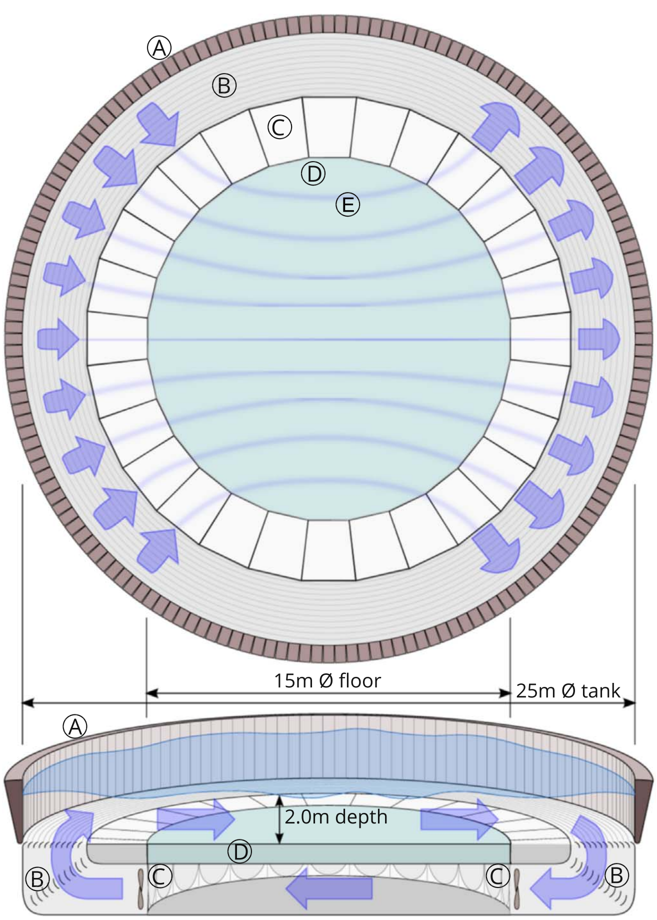

Fig. 1. Schematic of FloWave in plan and oblique section showing: (A) wavemaker paddles around circumference (168 Nr), (B) turning vanes and flow conditioning filters, (C) current drive impeller units (28 Nr), (D) buoyant raisable floor (15 mØ) below test area, (E) idealised streamlines of flow across tank floor.

2.2. ADV

An Acoustic Doppler Velocimeter (ADV) was used to measure the flow velocities in this study. The ADV used was a Nortek Vectrino Profiler capable of sample rates of up to 100 Hz and measuring multiple depth cells (Nortek-AS, 2016). The ADV operates by emitting a single acoustic pulse into the water. This pulse is reflected by particulate (termed back-scatters) in the water, assumed to be moving with the same flow speed, and the reflected pulse is detected by four angled transducers. The pulse is Doppler shifted according to the flow velocity and the four transducers allow the measurements of four flow

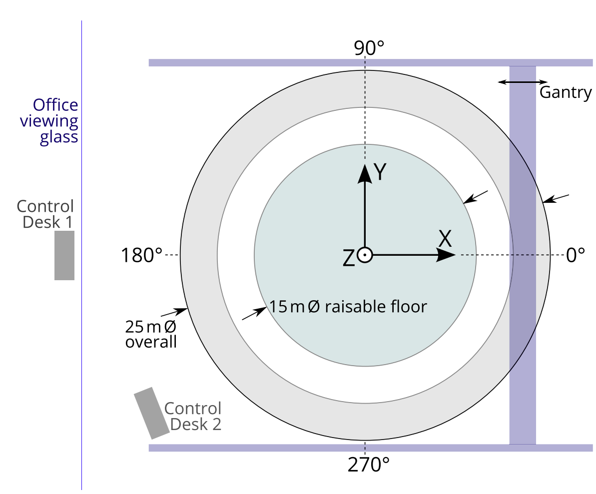

Fig. 2. Plan view of the facility including reference co-ordinates.