Ocean Engineering 75 (2014) 37–45

Contents lists available at ScienceDirect

Ocean Engineering

journal homepage: www.elsevier.com/locate/oceaneng

The use of conditioned axial flow impellers to generate a current in test tanks

Adam Robinson*, Ian Bryden, David Ingram, Tom Bruce

Institute for Energy Systems, Joint Research Institute for Energy, School of Engineering, The University of Edinburgh, King's Buildings, Mayfield Road, Edinburgh EH9 3JL, United Kingdom

ARTICLE INFO

Article history:
Received 21 February 2013
Accepted 30 October 2013
Available online 25 November 2013

Keywords:
Axial
Flow
Impeller
Propeller
Wave
Current
Test
Tank
Honeycomb
Hub

ABSTRACT

It is necessary to build a new generation of current and wave testing tanks to simulate more realistic sea conditions. Methods for wave generation and absorption are well established but those for current generation in this context are less established. One means of producing a current is by using an axial flow impeller. Unfortunately an impeller introduces into the flow unsteady velocities with high shear, strong turbulent fluctuations and hub effects, alongwith the useful thrust. In the experiment presented here honeycomb flow conditioning placed immediately downstream of the impeller is used to reduce the turbulence present in the flow. An Acoustic-Doppler Velocimeter (ADV) is used to measure three velocity components at a rate sufficient to characterise turbulence. A novel experimental arrangement using brush seals allows the ADV to penetrate the duct without compromising the integrity of the duct. A large number of point measurements were used to construct velocity profiles at various positions downstream of the honeycomb. Three different impeller speed settings were tested to investigate wake evolution. The results presented will aid the development of numerical models and increase understanding of the flow downstream of a conditioned impeller.

1. Introduction

Due to an increase in interest in off-shore energy generation a new type of current and wave testing tank is required. Testing scaled energy generation devices such as tidal turbines require a consistent and controllable flow.

An attractive method of producing a consistent and controllable liquid flow is using an axial flow impeller. Many studies have already been conducted investigating propeller wakes in relation to ship propulsion systems (Felli et al., 2002; Stella et al., 2000a). Stella et al. (2000a) described the wake flow near a propeller as exhibiting unsteady velocities with high gradients, strong turbulent fluctuations, and hub effects. Although the impeller provides the necessary thrust to accelerate the fluid, the unsteady velocities, strong turbulent fluctuations, and hub effects have to be reduced to acceptable levels before the flow can be used for testing. In the immediate wake of a propeller the point velocities can fluctuate by ±100% of the mean velocity with turbulent intensities of up to 1000%. The velocity profile in the test section of a tank needs to be stable, one directional and developed with a turbulent intensity of less than 10%.

It is possible to condition the flow to achieve the required characteristics though this always results in a loss of energy. One example of a flow conditioning method that is applicable in the context of a current and wave testing tank is honeycomb.

Honeycomb is a device that can be used to condition and straighten a fluid flow. It is a collection of segregated flow paths aligned in the flow direction; it eliminates swirl (Baker, 2005) and reduces the turbulent eddy size. The amount of materials used in the cross-section normal to the flow direction is minimised to reduce the loss of energy.

The configuration shown in Fig. 1 uses honeycomb to reduce the eddy size as well as remove the swirl induced by the impeller. Energy could be recovered by using a stator stage before the honeycomb, but at the speed at which the impeller operates, this energy recovery would be minimal (Hoshino et al., 2004).

When designing a current and wave testing tank it is important to predict how the flow will evolve after passing through the honeycomb as this determines how much length is required to develop the flow before it can be introduced into the tank or turned. This work can be used to aid the prediction of that evolution. This work is also of interest to numerical modellers who may wish to use these results to validate models or reduce the size of their computations by using the measurements reported here as boundary conditions.

In this paper an experiment is set up to measure the flow characteristics of a conditioned impeller for several speed settings. The area of interest for this investigation is highlighted in Fig. 1. Measurements are made using an Acoustic-Doppler Velocimeter

---

* Corresponding author. Tel.: +44 01316517112.
E-mail address: adam.robinson@ed.ac.uk (A. Robinson).

0029-8018/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.oceaneng.2013.10.016

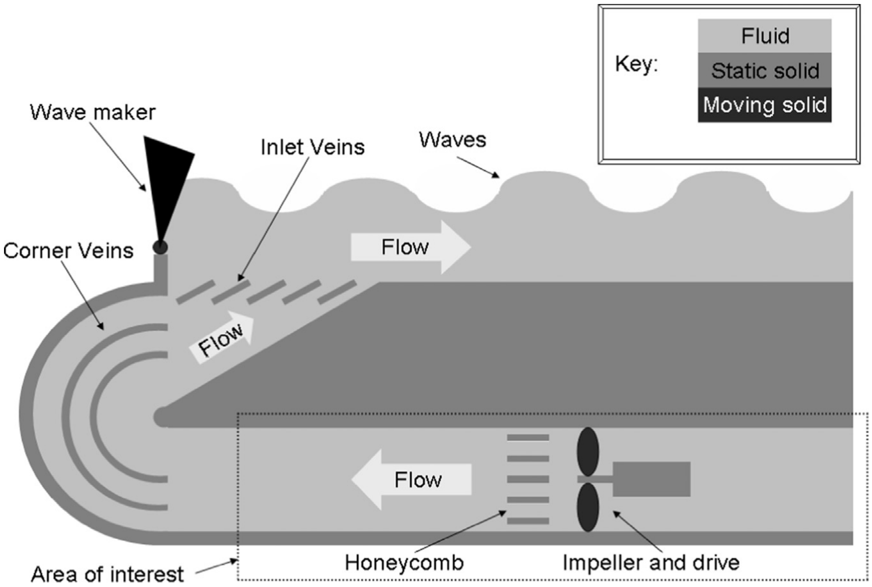

Fig. 1. Section through a potential current and wave testing tank.

(ADV) (Lohrmann et al., 1994). The ADV measures three components of velocity at a rate sufficient to characterise turbulence of the scale seen during these experiments.

1.1. *Propeller wake analysis*

Propeller wake analysis has been investigated many times as it is of great importance to those interested in the design of ships and their propulsion systems (Cenedese et al., 1988; Cotroni et al., 2000; Felli et al., 2002; Stella et al., 2000a).

In the past velocities in the propeller wake have been measured using Particle Image Velocimetry (PIV) (Cotroni et al., 2000; Di Felice et al., 2004; Felli et al., 2002; Stella et al., 2000a) and Laser Doppler Velocimetry (LDV) (Cenedese et al., 1988; Stella et al., 2000a, 2000b) due to the need for a non-intrusive measurement technique (Felli et al., 2002). PIV and LDV typically provide two components of velocity although it is possible to measure three components of velocity. LDV is a point velocity measurement technique. To assemble a true average measurement of the periodic and unsteady wake from a propeller it is necessary to relate the point measurement to the propeller position. To ensure that the measurement taken relates to a specific propeller position a triggering method called phase sampling is used (Cenedese et al., 1988).

PIV allows a simultaneous measurement of velocity through a 2D plane in the flow by comparing images of laser illuminated particles. Due to the length of time between each measurement image it is necessary to synchronise the imaging with the propeller position to produce good averaged data (Cotroni et al., 2000). Felli et al. (2002) used a stereo PIV setup to simultaneously measure three components of velocity. Stella et al. (2000a) measured two separate 2D planes sequentially then recombined the data in post-processing to give three components of velocity. ADV offers a point measurement equivalent to LDV and measures three components of velocity simultaneously. One of the potential issues with using an ADV is that the measurement head is intrusive. Although the ADV measures a volume centered 50 mm from the measurement head this intrusion might be an issue if significant swirl is present like that seen for an unconditioned propeller. The honeycomb used in this test should remove the swirl induced by the impeller; therefore the use of an ADV is acceptable.

Existing propeller wake studies measure downstream from the propeller face to the break-up of the helical tip vortex as these vortices dominate the flow behavior (Stella et al., 2000b). In these papers the noted measurement of the velocity profile evolution from the propeller does not stretch to the full recovery downstream. As this recovery distance is of critical importance to the design of water flumes this study needs to measure the wake further downstream of the propeller than the existing studies on unconditioned propellers.

Ducting is a method used to reduce thrust losses of a propeller in certain circumstances (Koç et al., 2009). The propeller in this experiment is mounted in a duct due to its being part of a current generation system, Fig. 1. Oweis et al. (2006a, 2006b) tested a very similar three-bladed, ducted propeller to the one reported here. The studies were however, concerned with tip-leakage flow, with no wake evolution data given. Koç et al. (2009) conducted an investigation into the velocity field of a impeller in air for which some wake data is provided. Nouri et al. (2011) also provided velocity field data for a impeller in air.

1.2. *Turbulence measurement*

Along with the wake evolution of velocity it is also important to have a knowledge of how the turbulence decays downstream of the honeycomb. There have been significant developments related to the accuracy of ADV in turbulent flows. Early ADV had problems relating to the raw signal being a combination of turbulent velocity fluctuations, doppler noise and signal aliasing, alongwith other disturbances. The data therefore could not be used without post-processing (Doroudian et al., 2007). Early ADV heads were also disruptive to the flow within the measurement volume (Rusello et al., 2006). Filtering techniques have been developed to improve the quality of velocity data for turbulent flows. An ADV requires three receivers to function in 3D. However the use of an extra receiver allows cross correlation of one of the measurement planes (Cea et al., 2007). This correlation data can be used to aid the filtering and improve accuracy (Rusello et al., 2006). Martin et al. (2002) found that the correlation value was affected by