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Physical scale model testing of a flexible membrane wave energy converter: Videogrammetric analysis of membrane operation

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ABSTRACT

In small-scale testing of wave energy converters (WECs), a key focus is on characterising the interdependent relationship between the primary converter and simulated power take-off system. If primary conversion is via the deformation of a flexible material, this task often requires non-contact measurement. In this paper, we introduce the development of an underwater non-contact measurement technique called videogrammetry, and its novel application to characterise the primary converter operation of a flexible membrane WEC. The work was part of Bombora Wave Power's concept validation wave tank tests at 1:15 scale. Details of the WEC and how it works is followed by an in depth description on applying underwater videogrammetry. A qualitative and quantitative analysis of membrane operation in a regular wave case is provided and discussed in terms of absorbed energy and power production. Two data sets are compared in this analysis. One data set is from videogrammetry and the other is airflow measurement data (airflow induced in the system due to membrane deformation converts wave energy to mechanical energy). This comparison quantifies the accuracy of videogrammetry, and also serves to verify airflow measurements that were used to determine performance indicators of the WEC throughout the entire test campaign. The results compare reasonably well. Sources of uncertainty for videogrammetry are discussed and improvements suggested. Preliminary best practices for applying videogrammetry in wave energy experiments are provided.

1. Introduction

Renewable energy, aside from the environmental benefits, is increasingly making economic sense. Wave energy is a viable form of renewable energy. Its potential and many methods for extraction have been extensively studied [1–5]; however, the levelised cost of energy (LCOE) needs to reduce if wave energy is to become economical. A key driver for reducing LCOE is technology convergence. Unfortunately, the wave energy industry has not converged to one or even several technologies. Without a clear solution, new wave energy converter (WEC) concepts continue to emerge. The first major advance in validating a new concept involves undertaking small-scale tests in hydrodynamic facilities such as wave tanks [6]. A key

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requirement is to estimate the power produced by the WEC, which involves characterising the relationship between incident waves, the primary converter, and the simulated power take-off (PTO) system. Characterising the dynamic behaviour of the primary converter is crucial to understanding both its operation and the WEC operation overall. This paper is focused on the application of a novel measurement technique to characterise the primary converter of a flexible membrane WEC. The work was part of Australian company Bombora Wave Power's concept validation wave tank tests.

Before introducing the measurement technique and experimental investigation, we will first briefly describe the design and operation of the WEC concept (further details of the device and proof of concept works are provided in [7]). Fig. 1 shows Bombora Wave Power's WEC prototype at the time of experiments in 2015.

The Bombora WEC is a bottom-fixed, fully submerged pressure differential device. It uses a flexible membrane and air turbine generator (power take-off (PTO)) system to convert wave energy to electricity. The membrane has a series of twelve cells separated into diaphragms containing air (Fig. 2a and b). As a wave peak passes over the device, an increase in pressure deforms the membrane, causing cells to deflate sequentially, pumping enclosed air (Fig. 2c). This pressure differential drives compressed air into a supply duct and around the closed circuit, which is ducted through an air turbine-generator PTO. Once the air has done work on the turbine, airflow returns back to a cell (restoring force) to start the cycle again. The full-scale device therefore operates in uni-directional flow.

Like many WECs, understanding the dynamic behaviour of the primary converter is crucial to understanding how the WEC produces power, and enabling future optimisation. In small-scale experiments, it is often necessary to quantify and qualify the primary converter operation in separate ways for verification of power estimates. Moreover, there is a lot value in obtaining as much information as practicable about the WEC system and subsystems in small-scale tests, where costs and timelines are relatively small. In the case of Bombora's small-scale experiments, characterising the flexible membrane operation required developing an underwater videogrammetry technique. This non-contact measurement approach was necessary due to the delicate nature of the membrane, whose dynamics would be greatly influenced if motion sensors were attached (i.e. accelerometers).

Videogrammetry is based on the principles of photogrammetry. Photogrammetry is essentially a method of making measurements from photographs [8]. By taking photos of an object or scene from different perspectives, a 3D reconstruction is possible from 2D photographs. Photogrammetry was developed for terrestrial mapping and surveying [9], but it is increasingly becoming a useful tool across many engineering disciplines to acquire accurate measurements of structures [10]. The technique has been proven accurate and reliable through developments made in space research into gossamer (flexible) structures [11–13]. Subsequent other demonstrations have emerged, for example in sail-boat research [14], where the authors apply photogrammetric modeling to empirically derive static shapes of a flying spinnaker in a wind tunnel. Using a number of fixed video cameras with a common field of view, dynamic measurement of an object or scene is possible, hence the term 'videogrammetry'. A 4D model (xyz + time) is the output of videogrammetric modelling. The technique is capable of monitoring dynamic structures that have displacements in the order of their size [10].

In the wave energy context, researchers at the Australian Maritime College (AMC), a specialist institute of the University of Tasmania, are applying videogrammetry to derive temporal and spatial maps of free surface wave fields produced by WEC radiation and diffraction effects [15–17]. Furthermore, videogrammetry has strong potential to replace current methods of measuring wave elevations using point-located wave probes [18].

Several technical components govern the successful application of photogrammetry. The following points list these components and related technical parameters, which have been adapted from [10] for videogrammetric modeling for wave energy experiments (Table 1).

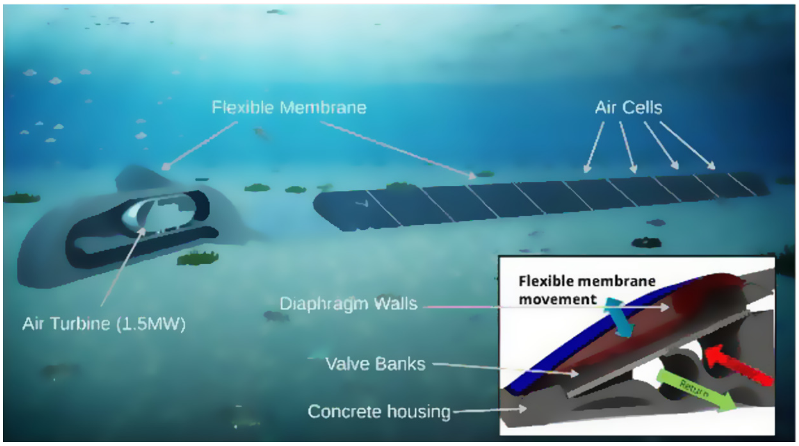

Fig. 1. Render of Bombora Wave Power's flexible membrane WEC prototype [7].

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