Energy 83 (2015) 89–103

Contents lists available at ScienceDirect

Energy

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

Hydrodynamic performance of an oscillating water column wave energy converter by means of particle imaging velocimetry

I. López [a, *], A. Castro [a], G. Iglesias [b]

[a] University of Santiago de Compostela, EPS, GICEMA, Campus Universitario s/n, 27002 Lugo, Spain
[b] School of Marine Science and Engineering, Plymouth University, Plymouth PL4 8AA, UK

ARTICLE INFO

Article history:
Received 22 September 2014
Received in revised form
16 January 2015
Accepted 29 January 2015
Available online 19 March 2015

Keywords:
Wave energy
Oscillating water column
Particle imaging velocimetry
Turbulent kinetic energy
Turbine damping
Tidal level

ABSTRACT

In an OWC (oscillating water column) wave energy converter the damping exerted by the turbine on the movements of the water column is one of the main factors, if not the main, affecting the power output. In this work the effects of the turbine-induced damping and the variation in the tidal level on the efficiency of the converter are investigated by means of a novel approach. PIV (particle imaging velocimetry) is used to determine the characteristics of the flow (the velocity and vorticity fields, and the kinetic energy) through a phase-averaging procedure. Then, Reynolds decomposition is applied to separate the velocity fluctuations for each test in order to estimate the turbulent kinetic energy. On this basis, we establish the relevance of the different factors—damping, tidal level and wave conditions—to the hydrodynamic performance of the OWC. We find that the turbine-induced damping is the factor that plays the main role: it affects the hydrodynamic behaviour of the chamber and thereby determines the amount of energy that the OWC is able to capture. In addition, the lip is found to be the critical element of the OWC chamber from the point of view of the structural design.

1. Introduction

Wave energy is one of the most promising marine energy resources, but it is not without difficulties. Wave energy exploitation is far from reaching maturity, with much work to be done in order to turn wave energy into a reliable and competitive energy resource. The efforts made over the last few years can be grouped into three fundamental research lines: resource characterisation [1–8], impact evaluation [9–11] and development of conversion technologies [12–16].

Among the wave energy conversion technologies, OWC (oscillating water column) devices [17] stand out by their simplicity and low maintenance cost relative to other WECs (wave energy converters). They consist of two elements: a partially submerged chamber with an underwater opening in the front and an air turbine connecting the upper part of the chamber with the atmosphere. Wave action causes the water column within the chamber to oscillate, which in turn forces the air trapped above the free surface to flow in and out of the chamber, driving the turbine in the process.

Turbine and chamber are, therefore, the key elements of an OWC wave energy converter. The majority of the works developed in this field were centred on the study of the performance of the OWC chambers [18,19] or air turbines [20–22], and greatly contributed to the state of the art. However, analysing the two elements separately does not permit to account for their interaction, and it has been proven that the turbine-chamber coupling, or in other words, the damping exerted by the turbine on the oscillations of the water column is the fundamental factor in improving the performance of an OWC [23–26].

In this work, an innovative approach based on PIV (particle imaging velocimetry) was applied to the study of an OWC. PIV is an optical technique which measures the velocity fields in fluids by determining particle displacements using a double-pulsed laser [27]. The laser illuminates a plane in the flow and two images are taken shortly one after the other. The particle displacements are obtained from these image pairs by an analysis algorithm and the velocity field is finally calculated from the known time difference between the images and the measured displacement.

The PIV technique has been widely used in coastal engineering, e.g., in connection with coastal structures [28–31], wave propagation [32,33] or wave breaking [34,35]. Its first application to OWC

* Corresponding author. Tel.: +34 982 285900.
E-mail address: ivan.lopez@usc.es (I. López).

http://dx.doi.org/10.1016/j.energy.2015.01.119
0360-5442/

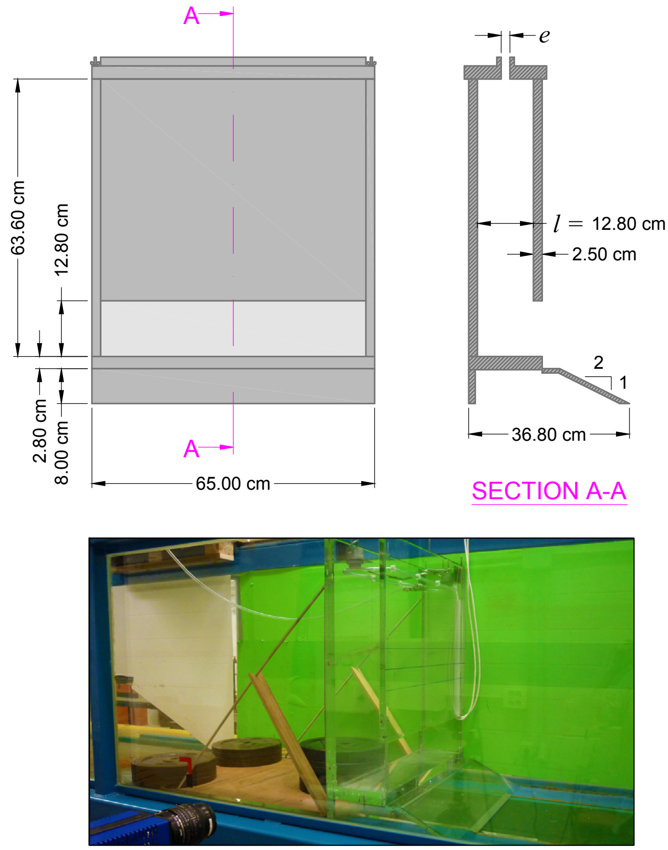

Fig. 1. Small-scale OWC model.

converters was carried out by Morrison [36], who used the PIV technique to calculate the kinetic energy and viscous dissipation for a simplified OWC scale model under different wave conditions. Graw et al. [37], with a similar set-up, also investigated geometry changes by varying the lip shape, submersion and angle. Recently, Fleming et al. [38,39] carried out an energy balance analysis to investigate the energy sources, stores and sinks for OWC geometry. Fleming et al. [40] also designed a phase averaging method by curve fitting using splines in order to process phase-clumped and discontinuous PIV data in an OWC. In sum, the parameters usually studied are the geometry of the device and the effects of the wave conditions.

In the present study, the PIV technique was applied to investigate the hydrodynamic performance of a small-scale OWC model. The main objective was to analyse the influence of the turbine-induced damping and the tidal level, whose effects on the hydrodynamic phase of the OWC have not been considered so far. In addition, the influence of the wave conditions was taken into account. The hydrodynamic performance was evaluated by means of the flow characteristics and the kinetic and turbulent kinetic energy, which were obtained through a phase averaging procedure. Finally, a comparison with the values of the capture factor obtained in previous works [26] was carried out.

2. Materials and methods

2.1. Experimental set-up

The physical model tests were carried out in the wave flume of the USC (University of Santiago de Compostela), with dimensions of 20 m (length) × 0.65 m (width) × 0.95 m (height). Waves are generated by means of a piston-type paddle equipped with an AWACS (active wave absorption control system) that absorbs reflected waves. The tests were conducted on a 2D model of a breakwater-integrated OWC (Fig. 1). This model reproduces, at a 1:25 scale, the vertical section of the OWC designed to be constructed at the Port of A Guarda (NW Spain) [26]. As short-wave hydrodynamic models (and therefore wave energy conversion models) are essentially governed by inertia and gravity effects, the model was designed based upon an undistorted Froude similitude [41]. Thus, a single length scale ($\lambda_l = 25$) was chosen. Additionally, the Froude similitude implies that

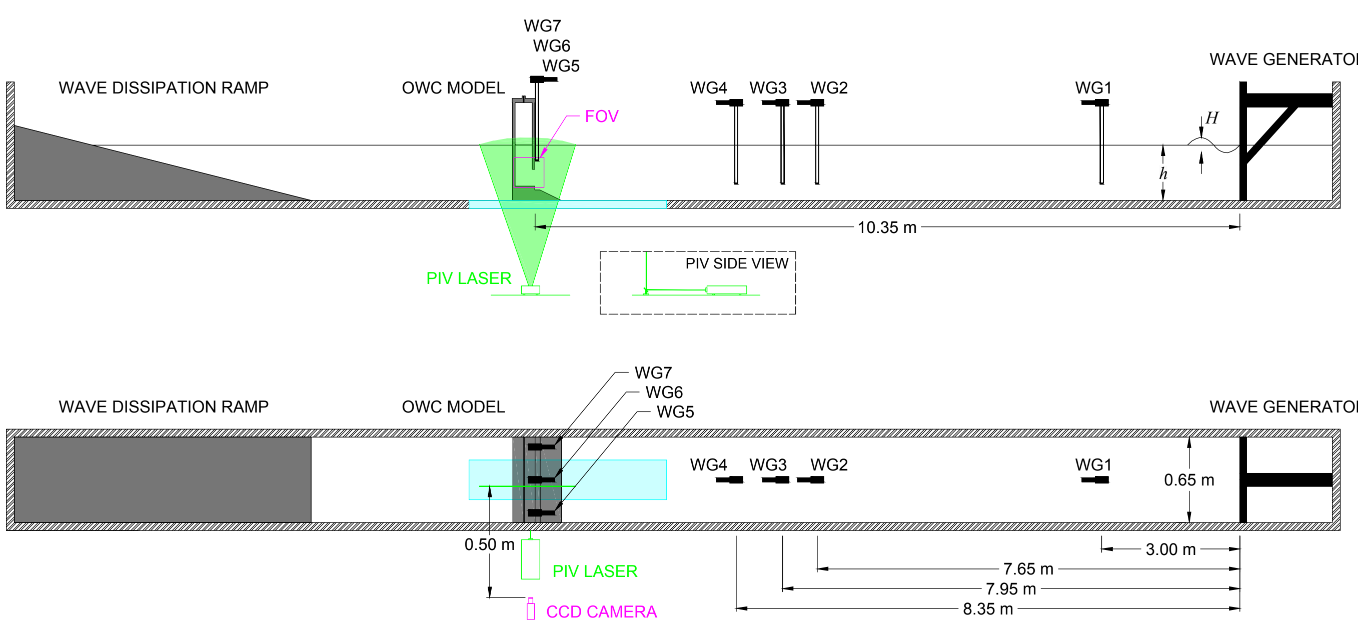

Fig. 2. Experimental set-up.