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Effects of the PTO inclination on the performance of the CECO wave energy converter

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ABSTRACT

This work investigates the performance of CECO, a third-generation wave energy converter of the oscillating bodies group. The power matrices of the device – which represent the wave power absorbed for different sea states – are obtained for five PTO inclinations. Then, the wave climate along the west coast of the Iberian Peninsula is characterized by means of the wave energy resource matrices. With the power matrices and the wave energy resource matrices, the performance of the device along the area of study is determined for each PTO inclination. To achieve this, the performance of CECO is assessed by means of a panel model based on the boundary element method, while the wave conditions in the area of study are assessed with a wave propagation spectral model. The results allow fulfilling an important knowledge gap concerning the impact of the PTO inclination on the performance of CECO, which was found to be very significant. In addition, the insight obtained will contribute to optimize future versions of CECO and other wave energy converters of the oscillating body type.

1. Introduction

Harnessing wave energy poses an enormous technological challenge and to date its exploitation is remarkably more expensive than harvesting most of the other renewable energy sources [1]. Although many wave energy converters (WECs) have been proposed over the past decades, it is unknown which design will be feasible in a commercial-scale [2]. On these grounds, the research and development of new WEC concepts and solutions continue.

The WECs can be classified according to different criteria [3]:

- the location: offshore, nearshore or onshore, and floating or submerged;
- the type of power take-off system (PTO): mechanical, hydraulic, pneumatic or directly electrical;
- their horizontal extension and orientation: point absorber or line absorber; and
- the type of energy for end use: electricity, water pumping, desalination of seawater, refrigeration, water heating or propulsion.

On the other hand, following [4], a WEC can be classified according to its working principle or its method of capturing wave energy into: oscillating water columns (*e.g.* Ref. [5]), overtopping devices (*e.g.* Ref. [6]) or oscillating bodies (OBs) (Fig. 1).

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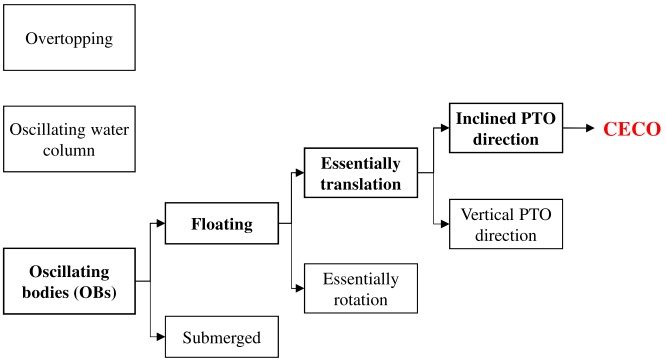

Fig. 1. Classification of WECs (adapted from Ref. [4]).

Despite the fact that the devices belonging to the OB group are generally more complex than the other WECs, these can harvest the energy associated to the more powerful wave regimes available at deep waters [4]. Among this group, two big sub-groups are well-differentiated: submerged and floating OBs. The former are mostly bottom-hinged pitching devices or flaps like the Oyster [7], but heaving buoys like the Archimedes Wave Swing have also been proposed [8]. As for the floating OBs, although there are some devices based on rotation (*e.g* Ref. [9]), most of them correspond to heaving buoys such as the IPS buoy [10] and the AWEC [11], among others. In general, the force associated to the vertical movements of the waves is the main source of energy in heaving buoys, while the horizontal one is utilized by bottom-hinged flaps [12].

With regards to the PTO configuration, most of the OBs adopt a vertical layout. However, an inclined direction presents several advantages, as it uses both the vertical and the horizontal force components of the water particles beneath waves. The concept of an inclined or sloped PTO was proposed for the first time by Ref. [13], who tilted the concept of the IPS buoy and restrained its motion to a single degree of freedom. On the basis of the latter idea, the advantage of a free floating WEC with sloped PTO against a vertical one was proved by Ref. [14].

Recently, a new OB with a sloped PTO was proposed: the CECO wave energy converter (Fig. 2). In this concept, the wave energy is absorbed by a floating body with its motions restrained to an inclined direction. The main elements of the floating body are two lateral mobile modules (LMMs) joined by a frame of tubular elements. To transform the absorbed energy into electricity, a rack-pinion system is used. The rack is mounted on the frame and the pinion is housed in the interior of the supporting element, where it drives an electric generator.

A key aspect of CECO is the inclination of its PTO, which is described as the angle (α) between the direction of translation of the floating part and the still water plane (Fig. 2). In the original concept, the floating part was meant to be tilted to a different angle depending on the wave conditions. Nonetheless, at the current stage of development, a proper mechanical system to vary the inclination has not been developed and there is no detailed study or sound evidence supporting the advantage of this feature. In fact, the effects of the PTO inclination on the performance of the device were not described until now.

The development of CECO started a few years ago with the physical model tests carried out at the wave basin of the Hydraulics, Water Resources and Environment Division of the Faculty of Engineering of the University of Porto, Portugal. The ability of CECO to harness wave energy was confirmed with an experimental proof of concept in Ref. [15]. Then, an improved physical model was built to investigate the influence of the incident wave conditions into the performance of the WEC [16]. During the experimental tests, it was inferred that the efficiency of the device varies depending on the angle of translation. However, the limited number of test conditions considered was insufficient to analyse this aspect properly.

More recently, numerical modelling was applied in the development of CECO. The influence of the damping induced by the PTO into the wave energy conversion process was investigated in Ref. [17], and the benefit of a configuration with an inclined PTO, in contraposition to a vertical one, was confirmed in Ref. [18].

As a previous step to optimization of the WEC, this work aims to verify and quantify the influence of the PTO inclination on the performance of CECO. For this purpose, the power absorption matrices of the WEC were obtained by means of the panel-model ANSYS Aqwa [19]. Bearing in mind that the CECO concept was idealized in Portugal, the Atlantic Coast of the Iberian Peninsula was chosen to estimate the performance of the device. The wave propagation numerical model SWAN was used with the purpose of characterizing the nearshore wave conditions over the area of study. Finally, the pilot zone for capturing the energy of ocean waves at São Pedro de Moel (Portugal) was considered to analyse in detail the performance of CECO.

The remainder of the present paper is structured as follows. Section 2 describes the original CECO concept and the model simulated in this work. The numerical methods applied to simulate CECO and to define the wave energy conditions in the area of interest are presented in Section 3 together with a description of the performance indicators used. The main results are presented in Section 4, including the power matrices of CECO for different PTO inclinations, maps of the energy absorbed by the device and the corresponding discussion of the results. Finally, Section 5 summarizes the main findings and presents future lines and priorities in the development of CECO.