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Wave energy conversion through a point pivoted absorber: Numerical and experimental tests on a scaled model

Domenico P. Coiro [a], Giancarlo Troise [b], Giuseppe Calise [a, *], Nadia Bizzarrini [a]

[a] Department of Industrial Engineering, Aerospace Division, University of Naples "Federico II", Via Claudio, 21, 80125 Naples, NA, Italy
[b] Seapower Scarl, Non-profit Research Consortium, Italy

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A B S T R A C T

This paper presents numerical and experimental tests on an innovative wave energy conversion (WEC) system for extracting electrical power from waves. It consists of a point pivoted floater which oscillates due to waves. Linked to the buoyant body, an electromechanical generator based on ball-bearing screw converts floating movements into electrical power. At first, an analytical description of the system arrangement is presented. Then, experimental tests on a scaled model have been performed in wave/towing tank facility and data from tests were used for comparison with data from numerical simulations: both potential flow and Unsteady Reynolds Averaged Navier–Stokes (URANS) numerical simulations were performed. These simulations have been performed in order to identify critical parameters for further WEC developments.

1. Introduction

Energy from waves represents an interesting field of investigation for renewable energy companies. Numerous recognized advantages are related to this kind of renewable energy source: relatively limited environmental impact and more predictable behaviour with respect to other energy sources are very attractive features for energy systems design. In particular, ocean waves often show relatively repeatable amplitude and frequency characteristics, dependent on the specific installation site.

In the design of wave energy conversion (WEC) system, many configuration parameters may be considered: buoyant body shape, overall system arrangement and type of energy conversion system are key-features. Point absorbers in heave represent one common type of WEC and many analytical studies [1] as well as numerical and experimental attempts have been done in order to optimize their shape and performances [2,3]. Pivoted type energy converters differ from pure heaving type since their motion is made by both horizontal and vertical translations so they do not fall in the category of pure heaving bodies, but they can be considered as being between a heaving point absorber and a terminator. Some investigations have been performed for this type of absorbers [4–6], whereas the only one deployed at full scale is the Wavestar device [7,8]. Wavestar system has an hydraulic PTO system based on oil as working fluid which necessitates the complex control mechanism described in Ref. [9]. The innovative system investigated in this paper, employs an electromechanical actuator based on ball screwing to convert mechanical motion directly to electrical energy. A study of a heaving device making use of ball screwing PTO is addressed in Ref. [17].

This work refers to the study and characterization of a pivoted type system based on an oscillating buoy of suitable shape; system arrangement effects are studied in order to optimize the energy conversion system. This kind of system is mainly intended for installation in suitable sea coastal areas. Operating principle ensures constructive simplicity and ease of operation; on the other hand, a suitable linear electrical conversion system will directly transform the linear motion to electrical energy.

This investigation relates to the power performance characteristic of a small scale model of the system under different operating conditions. A guidance on general towing tank test arrangement may been found in Ref. [10]. Some consideration on modelling and testing of WEC heaving based devices are considered in Ref. [11]. A general review of wave body interaction problems and numerical modelling techniques, particularly based on potential flow solution, may be found for example in Ref. [12] (even if specifically related to ship loads and seakeeping problems).

At a first stage, an analytical study for extracting kinematic

* Corresponding author.
E-mail address: g.calise@email.it (G. Calise).

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operating laws has been performed and, in order to completely define the numerical model, the behaviour of the Power Take Off system has been described. Towing tank tests are then presented and experimental data are collected for successive comparison with simulation results performed on two different configurations. Finally, computer aided simulations, both potential flow and Unsteady Reynolds Averaged Navier–Stokes (URANS) simulations, have been performed for purpose of comparison and validation of the model. The aim of developing a numerical model is to build a tool for WEC system parameters' analyses and possible future improvements. The workflow and results for selected ocean wave conditions will be shown in the present work.

2. Wave energy conversion system

2.1. Kinematic behaviour and governing equation

The primary system configuration is represented in Fig. 1. It consists of a floating body linked to a fixed frame and to the PTO (Power Take Off). Three hinges designated as A, B and C, allow the rotation of the body with respect to both the frame and the PTO: the hinge A allows rotation of the floater respect with the fixed supporting frame; the hinge B links the PTO to the connecting arms and permits relative rotation of its anchor point, keeping the PTO almost perpendicular to the arms, in the rest condition; finally, the hinge C joins the PTO to the fixed supporting frame.

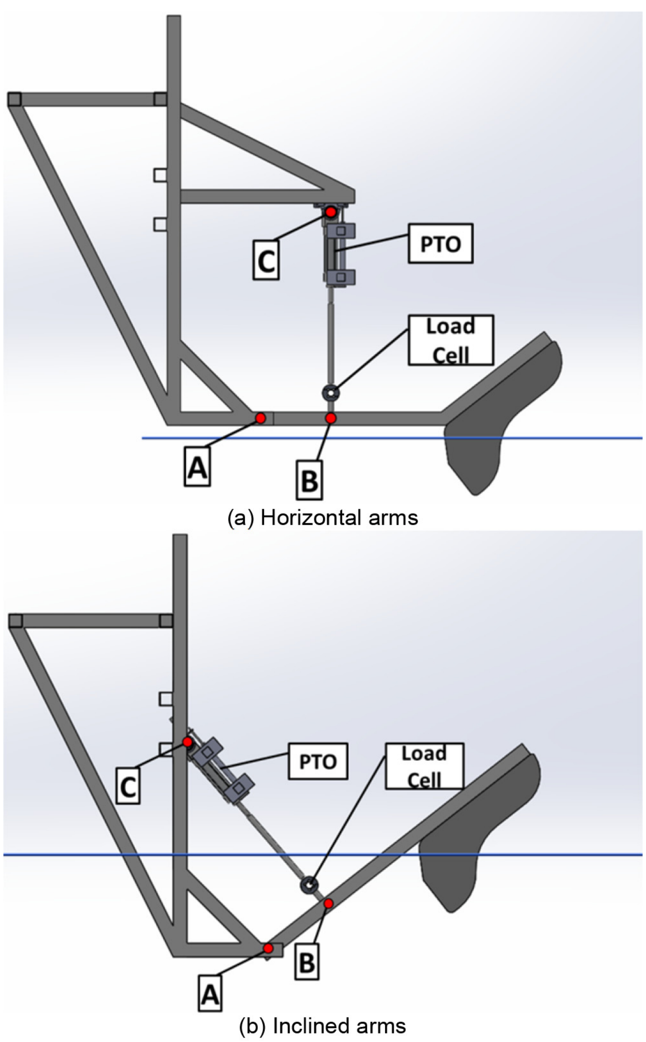

Fig. 1. Two tested configurations.

Two configurations, shown in Fig. 1, were used during the experimental tests and they differ in terms of different positions of the hinges A, B and C relative to the water free surface. Fig. 1a shows the supporting arms parallel to the water surface while Fig. 1b shows the system with supporting arms rotated respect to water surface. In both configurations, the PTO is perpendicular to the supporting arms.

The dynamic behaviour of the system may be described by the use of a 1 degree of freedom (DoF) equation, that is the equilibrium of moments around the hinge A axis:

$$I\ddot{\theta} + B\dot{\theta} + K\theta = M_{ext} + M_{PTO} \quad (1)$$

where:

- I is the sum of the pitch mass moment of inertia and associated hydrodynamic added inertia of floater;
- B is a linear damping coefficient taking into account radiation based fluid damping and includes a nonlinear viscous damping;
- K is the Archimedean hydrostatic restoration stiffness coefficient;
- M_{ext} is the incident and diffracted waves induced excitation moment;
- M_{PTO} is the moment due to the point pivoted PTO.

The PTO system was simulated during experiments by means of a controlled pneumatic actuator. The selected PTO system was controlled so as to produce a force response proportional to velocity variations (Eq. (2)).

$$P_{inst} = \vec{F} \cdot \vec{V} = K\vec{V} \cdot \vec{V} \quad (2)$$

The proportionality coefficient K may influence the overall behaviour of the system in response to wave action and may be set to a desired value through a controllable gain, via the actuator control software. Different operating conditions were investigated in order to estimate an optimal value for the proportionality coefficient.

In order to characterize the power production of the system, the absorber is equipped with a potentiometer that is linked to the buoyant body by means of a load cell: power is, then, indirectly measured as the product of force times velocity. Waves are measured by ultrasonic probes and device floater movements around its equilibrium positions are primarily measured by the potentiometer mounted on the piston during wave testing. (For some specific purposes, during the tests, other displacement measuring equipment have been used, such as a laser distance measuring system). All experimental measurements are collected and compared with numerical predictions.

3. Towing tank experimental tests

An extensive experimental programme was done using the University of Naples' Department of Industrial Engineering towing tank [13]. The towing tank is of length 140 m, depth 4.5 m and width 9 m with a wave generator capable of producing regular waves of selectable frequency and amplitude. Principal dimensions of the structure illustrated in Fig. 1b are shown in Fig. 2 and Table 1.

Experimental tests completed may be classified as “free response” and “frequency response” investigations.

It is worth noting that the floating body weight has been changed for some tests, and this will be indicated where it applies.