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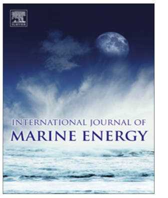

Development of a simplified analytical model for a passive inertial system solicited by wave motion

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ABSTRACT

This paper presents a theoretical and experimental investigation about the modelling of a 1:45 scale prototype Wave Energy Converter (WEC). An analytical model is implemented to describe its behaviour in a wave tank. The aim is to provide a contribution to modelling tools used for WEC characterisation and design. Hydrodynamic characterisation software is avoided in favour of a simpler and more versatile design tool destined to a wider range of users. Therefore, an alternative approach is presented, based on mechanical analogies and the use of Matlab/Simulink/SimMechanics environment. This analytical model was constructed using linear wave theory, coupled with a non-linear model for the device and its power take-off system (PTO). Assumptions on incident waves and geometric properties of the device were required and implemented on the basis of literature of naval architecture, ships stabilization and control issues. Simulation results were compared and validated with those obtained in the same range of experimental tests of the prototype in wave tank. Trends and values of both investigation techniques show a good agreement, indicating the validity of the methodology adopted and leaving space for future improvements of the same. Finally, as example of application, the model was applied in a show case in order to estimate the energy yield by the WEC if scaled to real size, using Froude scaling. Results are encouraging and show the viability of the proposed design.

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1. Introduction

Ocean energy is acquiring an increasingly important role within the Renewable Energy scenarios. A huge worldwide potential has been recognised for this kind of renewable source [1]. Oceans, in fact, cover approximately 70% of Earth's surface, and it is undeniable that Marine Energy could give an important contribution in a future decarbonized energy mix. The possibility to produce electricity from the sea is not a new topic. However, nowadays it is attracting more and more attention from academic and industrial sectors for being a clean energy source and for the need to boost the economy by creating new promising productive sectors [1]. Energy from the seas can be produced taking advantage of waves, tides, currents, temperature gradient and salinity gradient. Among these sources waves are surely the most tangible form to imagine the sea potential, and probably also for this reason one of the most investigated resources in the Marine Energy sector. Several concept devices, based on different working principles, have been studied and developed to exploit wave energy [2,3]. Basically three main categories exist for wave energy conversion purposes: oscillating water columns (OWC), overtopping systems (OTS), and oscillating body systems (OB). The first category exploits the air pressure oscillations caused by water rise and fall due to incident waves, while overtopping systems capture sea water in a reservoir above the sea level and then constrain it to flow through low-head turbines before to be released again to the sea. This work is focused on a converter belonging to the third mentioned category, the oscillating body systems. These devices extract power from waves using a power take-off system (PTO) that is activated taking advantage of the relative movement between two different parts of their structure which oscillate in response to incident waves. Therefore, this kind of devices is called *inertial*, since the inertial motion of a mass respect to a reference frame is used to generate electricity. Typically the functioning of those converters relies on the employment of a rotating and/or a translating mass, or alternatively a gyroscope. Although the operation principle is the same in both cases, an important difference exists between the two choices. In fact, gyroscopic systems require that part of the energy produced by the device is used to maintain the gyroscope itself in rotation for control and optimisation purposes [4], which consequently makes the device an *active system*. On the other hand, simple rotating and/or translating masses do not need energy to react to external solicitations, and are therefore *passive systems*. As a consequence, all the energy absorbed can be converted into electricity (within the limits of energy conversion efficiencies) because there is no need to use a part of the energy produced to feed the device itself. Currently several examples of inertial WECs exist and are employed [4–8]. In order to contribute to their development, and more in general to the entire Marine Energy sector, this paper focuses on the modelling work of a passive inertial Pendulum Wave Energy Converter (named "PeWEC"), developed and currently under investigation within a partnership agreement between ENEA (Italian National Agency for New Technologies, Energy and Sustainable Economic Development) and the Politecnico di Torino University (Italy). Finally, a preliminary estimate of expected energy production in the Mediterranean Sea is performed for a full-scale device.

2. System modelling

This section presents the experimental and theoretical premises that have been considered in order to investigate the device and create a proper model. The system studied, tested and modelled in this work can be idealised as half-cylindrical hull able to oscillate in pitch in response to wave motion. In its interior it contains a pendulum system, able to swing in one degree of freedom, which in turn is connected to an electric generator. The oscillation of the hull caused by the incident waves is transmitted to the internal pendulum. Hence, the relative motion between hull and pendulum activates a PTO system that produces electricity. Drawings of the hull and the PTO system are represented in Fig. 1.

2.1. The prototype

The 1:45 scale prototype of the inertial device has been designed and projected by ENEA and posteriorly tested in the wave channel of the Politecnico di Torino, using regular waves for different

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