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Optimising power take-off of an oscillating wave surge converter using high fidelity numerical simulations

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ABSTRACT

Oscillating wave surge converters are a promising technology to harvest ocean wave energy in the near shore region. Although research has been going on for many years, the characteristics of the wave action on the structure and especially the phase relation between the driving force and wave quantities like velocity or surface elevation have not been investigated in detail. The main reason for this is the lack of suitable methods. Experimental investigations using tank tests do not give direct access to overall hydrodynamic loads, only damping torque of a power take off system can be measured directly. Non-linear computational fluid dynamics methods have only recently been applied in the research of this type of devices. This paper presents a new metric named wave torque, which is the total hydrodynamic torque minus the still water pitch stiffness at any given angle of rotation. Changes in characteristics of that metric over a wave cycle and for different power take off settings are investigated using computational fluid dynamics methods. Firstly, it is shown that linearised methods cannot predict optimum damping in typical operating states of OWSCs. We then present phase relationships between main kinetic parameters for different damping levels. Although the flap seems to operate close to resonance, as predicted by linear theory, no obvious condition defining optimum damping is found.

1. Introduction

Among the wide range of wave energy converters (WECs) the class of oscillating wave surge converters (OWSCs) has significantly gained importance in the last years. Both, on scientific and commercial level concepts of OWSCs have been presented and are subject to ongoing research. Some examples to be mentioned are WaveRoller by AW-Energy [1,2], bioWAVE (BioPower Systems) or Oyster by Aquamarine Power [3]. In contrast to e.g. heaving buoys or oscillating water column devices, OWSCs are driven by the horizontal particle motion of the wave. They are therefore usually deployed in the near-shore environment where the horizontal particle motion is amplified [4].

Subject of this investigation is a generic flap-type OWSC similar to Oyster. It consists of a buoyant surface-piercing flap that pitches back and forth around a hinge close to the seabed driven by the torque of incoming waves. Two hydraulic pistons attached to the landward side of the flap serve as a power take-off system (PTO). During operation they act a constant damping torque on the device that is in phase but acts in opposite direction than velocity. The pressurised water powers a

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hydro-electric generator on-shore. For further information on the technical details of the device and its development, see [5,6].

One area of interest of OWSC hydrodynamics is the instantaneous characteristics of wave excitation or the torque exerted by the wave on the device while it oscillates freely or damped by the PTO. Specific features of interest are its characteristic course during a wave cycle, its magnitude and its phase relations to other kinetic quantities. It might be unexpected in the first place that such fundamental quantities have not been explicitly identified so far, even though they are crucial for the accuracy of power prediction models or detailed load analysis. However, a closer look at common research techniques reveals that the reason therefore lies in their inherent limitations. Experimental wave tank tests suffer from a lack of appropriate measuring techniques to capture the instantaneous wave torque and the range of validity of linear BEM codes like *WAMIT* or *NEMOH* is typically exceeded in operating conditions due to non-linear wave characteristics or high rotation amplitudes of the device.

Many of these limitations can be overcome by the use of fully-viscous non-linear CFD models that model the device and the surrounding fluid. Recent studies prove the feasibility and accuracy of RANS finite volume codes using the volume of fluid method (VOF) to model the free surface interface. While [7] present qualitative comparison with experimental data in monochromatic seas, [8] present simulations in irregular waves similar to typical operating conditions and quantify differences between experimental and numerical data with a model coefficient of 0.98.

Despite the high detail and accuracy of such methods, long-term performance modelling is not feasible for engineering tasks due to the high computational cost [9]. Their application should thus aim at a better overall understanding of the hydrodynamics of OWSCs in order to improve the accuracy of existing simple models or support specific engineering tasks.

In this paper we first present a review of previous investigations on the topic of wave excitation and PTO optimisation and state the limitations that emanate from other applied methods. We then give a brief description of the applied CFD model and outline the computation of wave torque based on the cell-wise data provided by the numerical simulations. Furthermore we discuss the influence of PTO torque on the magnitude and phase relations of wave torque. The latter is based on power optimisation test series of an OWSC operating in two representative monochromatic waves. For the sake of clarity the degrees of freedom and certain descriptive terms of an OWSC are given in Fig. 3.

2. Definition of wave torque

Before discussing the wave excitation of an OWSC, we define this term for our purpose in more detail. Within literature several terms such as '*fluid pressure torque*', '*hydrodynamic torque*' or '*wave excitation torque*' are used that often mean the same thing but sometimes differ in crucial details.

In this paper we will use the terms *hydrodynamic torque* and *wave torque*.

The term *hydrodynamic torque* T_h shall correspond to the overall torque the surrounding water acts on the device. An equation of motion directly equivalent to Newton's famous second law of motion is written as follows:

$$T_h = (I)\ddot{\theta} + T_g + T_{PTO}, \qquad (1)$$

with the inertia I of the flap structure, $\ddot{\theta}$ the acceleration of the flap, T_g the torque due to gravitation and T_{PTO} the torque component due to the power take off system. This formulation is used for example in CFD simulations, where the overall hydrodynamic forces are available.

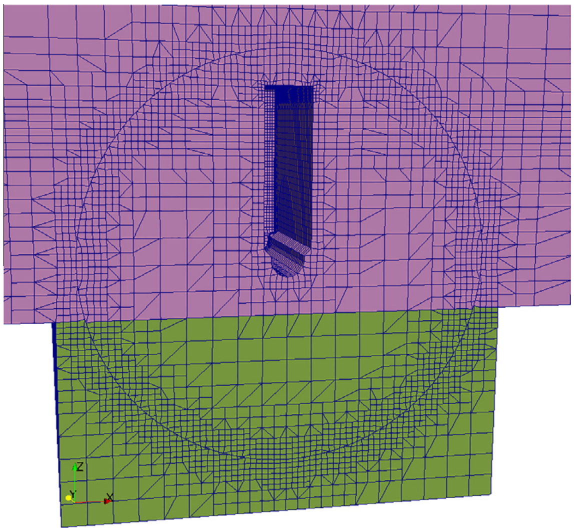

Fig. 1. Mesh around the flap. Colour indicates the variable sand used to model the sea floor inside the rotating domain.