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Simulation of a Self-Adaptively Controlled OWC in a Nonlinear Numerical Wave Tank

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ABSTRACT

An oscillating water column (OWC) wave-energy device is simulated in a 2D numerical wave tank. The fluid flow modelling is fully nonlinear. A new wave generation by spinning dipole is proposed; when coupled to a robust wave absorption technique, it permits long-term simulations without energy accumulation in the flume. The turbine power takeoff mechanism is driven by a self-adaptive controller. The technique initially developed for active piston wave absorbers is applied successfully to OWC power plants. It is based on a Kalman filter frequency tracking algorithm. This control compares favorably with more conventional open-loop systems.

INTRODUCTION

It has been shown in several published studies that the overall efficiency of wave power plants can be largely improved by a suitable on-line control of the power takeoff mechanism (e.g. Perdigão and Sarmento, 1993). In the case of oscillating water column (OWC) devices, the maximum power is recovered when the inner pressure can be kept in phase with the diffraction flow. In the present study, we assume the ability to control the air flow rate across the turbine according to a feedback of the pressure in the chamber. For simple 2D devices, the transfer function of such an ideal controller can be derived in the frequency domain, under the usual assumptions of the linear potential flow theory (Evans and Porter, 1995). Unfortunately, the time domain counterpart of the ideal controller is not causal, making it practically unrealizable.

This problem is not specific to OWC devices, but is a general property of ideal (i.e perfect) wave absorbers (Naito and Nakamura, 1985). It was also encountered when devising a control law for the regulation of a piston wave absorber by Clément and Maisondieu (1993). To solve the latter problem, a self-adaptive strategy was presented at the last ISOPE conference (Chatry et al., 1998a). It is based on the on-line tuning of the regulator with respect to an instantaneous frequency estimated by a robust extended Kalman filter. This technique was first extended to the control of OWC power plants in a linear theoretical framework by Chatry et al. (1998b).

In the present paper, the Self-Adaptive Feedback Feedforward (SAFF) control strategy is implemented in a fully nonlinear numerical wave tank (NWT). This simulation code (CANAL) was already used by A.H. Clément (1997) to simulate the nonlinear radiative response of such a 2D OWC plant. Since then, a new option dedicated to the simultaneous wave generation and absorption by discrete internal singularities has been developed in this computer code in order to permit the long-term run of diffraction-radiation processes (Clément, 1999). This new method is a numerical alternative to the existing method for generation and absorption by a single device in physical basins (Skourup and Schäffer, 1997). It is presented here, together with the results of long-term nonlinear simulations of a generic 2D OWC plant activated by random incoming waves.

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KEY WORDS: gravity waves, wave absorption, oscillating water column, wave energy, adaptive control, perfect fluid, free surface, numerical wave tank, fully nonlinear.

MATHEMATICAL FORMULATION

Let us first describe the problem to be solved, before deriving the governing equations. The OWC power plant under consideration is a fixed, bottom-standing structure featuring an inner chamber open to the sea by a submerged aperture between the front-wall lower tip and the sea bottom (Fig. 1). The problem will be treated as a 2D one in the vertical XY plane. The incident waves are supposed to come from infinity (left), and the reflected part of the wave energy, not absorbed by the device, is supposed to return to infinity. Such a setup is commonly named a terminator in the wave-energy community (Sarmento and Falcão, 1985).

As a first consequence, the left end of the numerical wave flume must perform as a wave maker and a wave absorber at the same time. This is achieved in our computer code (CANAL) by

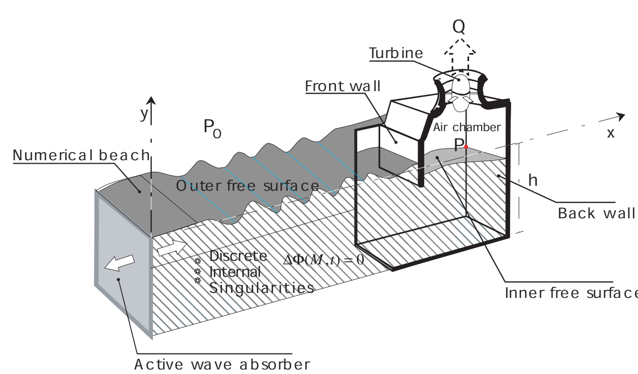

Fig. 1 Definition sketch