

An Experiment-Based Time-Domain Mathematical Model of OWC Power Plants

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ABSTRACT

A linear time-domain model based on model experiments is developed and experimentally validated. The flow displaced by the internal water free-surface is decomposed in the radiation and diffraction flows. The radiation flow is expressed as a convolution integral involving the air-pressure time-derivative and the radiation impulse response function. This function has been estimated by a set of transient experiments on a 1:35 scale model. Results from energy absorption experiments on the same model were used to validate the mathematical model. Illustrative results are presented concerning the performance of an OWC power plant equipped with a Wells turbine and a bypass valve where excessive pneumatic power is dissipated in very energetic seas. The present paper is an extension of a previous one (Sarmento, 1991).

INTRODUCTION

After 20 years of research and the construction of a few pilot power plants of the Oscillating Water Column (OWC) type, three OWC pilot plants are going to be built in Europe. These are partly funded by the JOULE nonnuclear energy R&D programme of the European Union. More demanding design procedures are required for these plants. Moreover, more sophisticated means of analysis will be required during the experimental operation of the power plants. This paper aims to contribute to the increase of quality of both the design and operation tools required by efficient and safe OWC power plants.

Wave energy studies have been based on mathematical and experimental modelling. Frequency-domain and time-domain models have been developed in the past as tools to support fundamental research related to specific or generic type of devices (Evans, 1982; Count and Evans, 1984; Sarmento and Falcão, 1985; Malmo and Reitan, 1985; Evans and Porter, 1995). These studies are mostly based on analytical methods and have been performed on the basis of the linear theory of surface waves, considering simplified geometries and a flat bottom. More recently You (1993) developed a numerical model based on the boundary element method to compute the hydrodynamic performance of near-shore OWC devices. This model takes into account the effects of variable bottom topography. Yu et al. (1995) used results from this model to develop a state-space model of order five, which was successfully applied to the shoreline pilot plant of Dawanshan island in the South China Sea. One of the first nonlinear approaches is being developed by Clément (1995) for flat-bottom, two-dimensional geometries.

The above models require, in general, a certain number of simplifications, some of which are not compatible with the design stage of the devices. For this reason, the design of the pilot plants constructed so far has been based on a fairly complete programme of tank testing. Tank testing allows the optimisation of the geometry and dimensions of the device and the assessment of some of

the main characteristics of the power takeoff equipment (as for instance the ratio between the pressure drop and the flow across the turbine). The main limitation of experimental testing is the difficulty of having a detailed simulation of the power takeoff equipment. This equipment is usually simulated by a device that performs similarly with regard to the hydrodynamics of the OWC and not with regard to the details of the equipment itself. (The turbine is simulated by a device where an equivalent amount of the air pneumatic energy is dissipated in a similar way, usually nonlinear orifice plates or linear filters — Sarmento, 1992.)

The second section of the paper presents a time-domain mathematical model based on linear wave theory and on model experiments in a wave tank. The model retains both the advantages of mathematical modelling and those of experimental testing. These are the good hydrodynamic description provided by the experiments, and the flexible, reliable and realistic descriptions of the power takeoff equipment and control procedures provided by the mathematical model.

The mathematical model solves the equation of continuity of the air in the time-domain. The flow displaced by the internal water free surface is decomposed into the usual two terms: the diffraction flow (flow due to the incident and diffracted waves in an air chamber open to the atmosphere) and the radiation flow (flow due to air pressure fluctuations in otherwise calm water). The radiation flow is computed as a convolution integral involving the impulse response function and the time derivative of the air pressure. The impulse response function is estimated by means of transient experiments, using a method described in the third section. The experimental procedure and the estimate of the impulse response function are validated with results from energy absorption experiments in an irregular wave tank. Nonlinear effects, both on the diffraction flow and radiation flow, are investigated. These, as expected, are not severe and occur mainly for very high waves and high-pressure fluctuations. Some illustrative results concerning the operation of an OWC power plant equipped with a Wells turbine and a bypass valve (where excessive pneumatic energy is dissipated in very energetic seas) are presented in the fourth section.

MATHEMATICAL MODEL

We consider a fixed, bottom-standing OWC device. The seabed is assumed to be of arbitrary depth and shape. The analysis is

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KEY WORDS: Wave energy, OWC, linear modelling, transient experiments.