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In-situ orifice calibration for reversing oscillating flow and improved performance prediction for oscillating water column model test experiments

Alan Fleming *, Gregor Macfarlane

National Centre for Maritime Engineering and Hydrodynamics, Australian Maritime College, University of Tasmania, Australia

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ABSTRACT

Performance characterization of oscillating water column (OWC) wave energy converters (WEC) is commonly assessed by conducting physical scale model experiments of OWC models fitted with orifice plates to the air chamber to both; simulate the power take off (PTO), and measure the air flow rate. Generally it is assumed that a single calibration factor can be used for bi-directional air flow measurement, however this paper shows the assumption can be in-accurate and that it is necessary to have separate inflow and outflow calibration factors. This paper presents (i) a novel method for in-situ calibration of an orifice and (ii) a simple algorithm to reduce noise during air flow reversal (low air chamber pressure differential). Application of this technique results in more accurate flow rate prediction and consequently, better prediction of the power absorbed by the power take-off for OWCs.

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1. Introduction

Model testing of oscillating water column (OWC) wave energy converters at small scale (1:100–1:30) presents the issue of only a small amount of power being available (~10 W) for conversion at the power take-off (PTO). Due to scaling effects, system inefficiencies and manufacturing complications the PTO is normally simplified as a simulated PTO [1,2]. The simulated PTO is considered to dissipate the Froude scaled equivalent to the energy dissipated (converted/wasted) at full scale by the actual PTO [3]. Simulated PTO's are chosen either for their simplicity, or ability to match the pressure/flow characteristics of the design full scale turbine (PTO) [4]. An orifice plate is commonly used to simulate the PTO due to the simplicity in design [2,5–8]. The orifice has a non-linear flow characteristic in that the differential pressure across the orifice is proportional to the square of the flow through the orifice. Power dissipated by the orifice is proportional to the product of pressure differential across the orifice and the volume flow rate (flux) of air through the orifice [6].

For an OWC, measurement of air volume flux is more difficult using standard flow measurement equipment due the flow continuously changing in both magnitude and direction. Air volume flux may be derived from either:

a. Water free surface displacement inside the OWC chamber using one or more wave probes [5], or video frames of the free surface displacement [9];
b. Pressure transducer data using a calibrated orifice [6,7].

* Corresponding author.
E-mail address: alanf@amc.edu.au (A. Fleming).

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There are several arguments why the use of pressure data is preferred to wave probe data for calculation of OWC air volume flux:

- Pressure data is easier to obtain;
- It is not necessary to make assumptions about the nature of the water free surface inside the chamber. Measuring the free-surface will lead to greater uncertainty and potentially the introduction of error in the calculated value.

However since the air flow oscillates in both magnitude and direction, modelling the relationship between pressure and flow becomes more complicated. In particular; it is known that pressure may vary depending on the physical position of the pressure sensing instrumentation [10–12]. Fig. 1 demonstrates a mass inbalance using data from pressure transducers which monitored pressure inside the air chamber for a model OWC tested in monochromatic waves. The pressure signal is drawn as a solid line with outflow shown in blue and inflow shown in green. Inflow is also inverted as a dashed red line to better enable comparison with the outflow pressure signal. If assuming constant density and using a typical orifice equation (Eq. (1)) the cumulative sum of the pressure will be proportional to volume flux, to obey with the assumed mass balance for an OWC the slope of the previously mentioned cumulative sum should be zero, since on average volume displaced is also zero.

This paper describes a process to use measured air chamber water surface elevations for in-situ calibration of air flow measurement via determination of air flow coefficients based on air chamber pressure differential measurement. Further; the mass balance error is shown to be reduced by using flow coefficients separately for both inhalation and exhalation.

2. Apparatus

The methods presented in this paper consist of two stages; the first being the derivation of flow coefficients using water column displacement data, the second being the estimation of air volume flux application of the flow coefficients. Hence it is not always necessary to complete the first operation if the orifice flow coefficients are already known with a level of certainty. Note that the flow coefficients presented here are strictly only compatible with the orifice used (and perhaps other unknown factors).

Data for this paper is drawn from experiments with a greater ultimate purpose which demonstrates the 'in situ' nature of this paper. Experiments were performed on four separate 1:30 scale deep water forward-facing bent-duct OWC models (see Fig. 2 and Table 1 for details). The primary purpose of the experiments was a PIV investigation on the effect of altering OWC geometry [13].

Experiments were conducted in the Australian Maritime College (AMC) towing tank which is 100 m long, 3.5 m wide and 1.5 m deep. A hydraulically driven paddle type wave maker is located at one end of the tank and a passive sloped beach is located at the other end. The models were positioned at the centre of the tank crosswise (one at a time) and approximately 60 m from the wave paddle and with the opening of the model facing the incoming waves.

Each OWC was fitted with an array of 5 resistance type wave probes inside the chamber to measure water column heave (see Table 2 for locations), and a single (external) wave probe adjacent to the front chamber wall. Two Endevco pressure transducers (2 psig Model 8510B-2) monitored chamber differential air pressure in the top plate of the chamber at the cen-

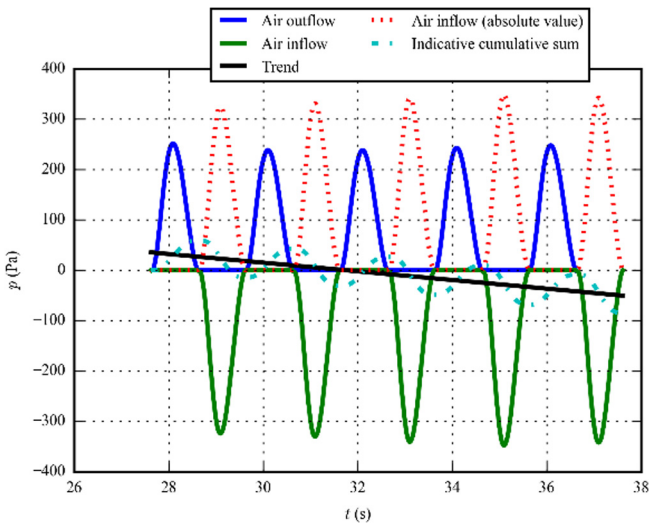

Fig. 1. Typical time series differential air chamber pressure for a model scale oscillating water column.

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