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Numerical and Experimental Study of a Horizontal Cylinder-type Wave Energy Converter with Off-centered Axes of Rotation

Haeng Sik Ko, Il-Hyoung Cho and Yoon Hyeok Bae
Department of Ocean System Engineering, Jeju National University
Jeju, Korea

This paper presents a numerical and experimental study of the hydrodynamic behavior and performance of a horizontal cylinder-type wave energy converter (WEC) with off-centered axes of rotation. The efficiency of the horizontal cylinder-type WEC with off-centered axes of rotation is comparable with the asymmetric WEC. Numerical calculations based on the OpenFOAM open source computational fluid dynamics code were used to analyze the dynamic behavior of the horizontal cylinder-type WEC with off-centered axes of rotation in the wave field. The numerical wave tank is modeled with the eccentric horizontal cylinder-type WEC constrained to a single degree of freedom (pitch mode). interDyMFoam, an OpenFOAM solver that solves the Reynolds-averaged Navier–Stokes equations for two incompressible phases using the volume of fluid technique and an arbitrary mesh interface, was used for simulating the rotational motion of WEC. The effects of both the position of the center of rotation and the incident wave height were evaluated by comparisons of the results of the free decay tests and the response amplitude operators. The results obtained by numerical simulations were compared with the experimental data. Moreover, body motion was analyzed in the frequency domain considering the linear viscous damping coefficient obtained from the free decay test, and the obtained results were also compared with experimental data. Furthermore, energy losses as a result of different incident wave heights were investigated considering the nonlinear motion response. The extracted powers of the horizontal cylinder-type WECs with off-centered axes of rotation were estimated by using the optimal power take-off damping coefficients obtained from the equation of motion in the frequency domain.

INTRODUCTION

Climate change caused by increased levels of CO_2 in the atmosphere as a result of the use of fossil fuels has made research on renewable energy electricity generation mainstream. Wave power is a potential renewable energy resource, and the power that can be harnessed globally from waves has been estimated to be greater than 2 TW (Thorpe, 1999). Several wave energy converters (WECs) based on various designs and concepts have been developed to obtain improved energy conversion efficiency (Drew et al., 2009). Recently, the large-scale WEC has advanced beyond the use in research applications only to commercial deployment in the real ocean environment (Pecher et al., 2014).

Numerical simulations using the latest techniques can anticipate the behavior of WEC accurately for solving hydrodynamic problems. To date, most numerical simulations have been carried out with hydrodynamic models based on the linear potential flow theory. Retes, Merigaud, et al. (2015) added a correction term to analyze the nonlinear Froude–Krylov force. The parameterized viscous force term was considered by Bhinder et al. (2015) and Nematbakhsh et al. (2015). With advances in computational performance, computational fluid dynamics (CFD) studies considering the highly nonlinear wave and viscous flow effects have been actively conducted. Many commercial CFD software packages such as ANSYS Fluent, CFX, and STAR-CCM+ have been widely used for simulating WECs. Currently, OpenFOAM®, which is an open source code under general public license, is also being used, and its accuracy has been verified by comparison with experimental results.

Except for the latest version (OF-5.0), OpenFOAM does not include the boundary conditions for wave generation and absorption. Jacobsen et al. (2012) developed Waves2FOAM, an additional module that can generate regular and irregular waves and absorb the reflected waves with a relaxation zone.

Higuera et al. (2013) developed IHFOAM, which can decrease the computational cost of simulations by using active wave absorption. Higuera et al. (2014) added a module for analyzing porous media in the wave dynamic field. Higuera et al. (2015) developed the upgraded IHFOAM to include multi-paddle piston-type wave generation.

Eskilsson et al. (2015) simulated the wave overtopping of the Wave Dragon model and calculated the discharge according to the different crest heights of the wave. Schmitt and Elsaesser (2015) carried out simulations using the Oyster model (oscillating wave surge converter) with an arbitrary mesh interface (AMI). Palm et al. (2016) presented the methodology of coupled OpenFOAM and mooring analysis based on a higher-order finite element model.

Salter duck is a typical terminator WEC that has already theoretically been shown to convert rotation into electricity with a high efficiency of more than 80% (Salter, 1974). These multiple ducks consisting of rotors coupled with a weather-vaning system have been tested and commercialized by Pecher et al. (2014).

On the other hand, the hybrid-type Salter duck including a desalination system inside the duck has been investigated (Cruz and Salter, 2006). The circular cylinder with an off-centered axis of rotation has also been investigated (Lucas et al., 2009). The principal advantage of this design is the lower cost of the manufacturing process compared with the original Salter duck. The performance is not very different from that of the original duck.

The aim of this paper is to numerically and experimentally investigate the horizontal cylinder-type WEC off-centered axes of rotation that give rise to an asymmetric dynamic behavior despite the symmetric body shape. The results of laboratory tests were compared with the numerical results obtained from OpenFOAM

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KEY WORDS: Cylinder-type WEC, off-centered axes rotation, OpenFOAM, RANS, extracted power, PTO.