International Journal of Offshore and Polar Engineering (ISSN 1053-5381)

Vol. 20, No. 4, December 2010, pp. 247–255

http://www.isope.org/publications

IPS 2-Body Wave Energy Converter: Acceleration Tube Optimization

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This paper presents the geometry optimization of the acceleration tube of an IPS buoy wave power converter, a 2-body point absorber oscillating in heave. The optimization objective is the accomplishment of a good relation between the energy extracted from a specific wave site and the submerged volume of the device. The equations of motion for the 2 degrees of freedom are derived in the frequency domain. The power extraction from real sea waves was simulated using an energy spectrum and the probability distribution of a wave climate. An optimal geometry of the acceleration tube is presented.

INTRODUCTION

The concept of a point absorber, introduced by Budal and Falnes (1975), is a wave energy converter (WEC) whose horizontal dimensions are much smaller than the representative wavelength. Compared with larger WEC, point absorbers in general are characterized by a narrower resonance bandwidth while exhibiting a larger (and more advantageous) ratio between absorbed energy and structural volume. An adequate device control can increase this ratio.

In its simplest version, the body reacts against the bottom. In deep water (say, 50 m or more), this may raise difficulties due to the distance between the floating body and the sea bottom. Multibody systems may then be used instead, in which the energy is converted from the relative motion between 2 oscillating bodies. One of the most interesting 2-body point absorbers for wave energy conversion is the IPS buoy, invented by Noren (1981) and initially developed in Sweden by the company Interproject Service (IPS). It consists of a floater rigidly connected to a fully submerged vertical tube (the so-called acceleration tube) open at both ends. The tube contains a piston whose motion relative to the floater-tube system (motion originated by wave action on the floater and by the inertia of the water enclosed in the tube) drives a power take-off (PTO) mechanism. The same inventor later introduced an improvement that significantly contributes to solving the problem of the end-stops: The central part of the tube, along which the piston slides, bells out at either end to limit the stroke of the piston (Noren, 1988). A half-scale prototype of the IPS buoy was tested in sea trials in Sweden in the early 1980s (Cleason et al., 1982).

The AquaBuOY is another wave energy converter, developed in the 2000s, that combines the IPS buoy concept with a pair of hose pumps to produce a flow of water at high pressure that drives a Pelton turbine (Weinstein et al., 2004). A prototype of the AquaBuOY was deployed and tested in 2007 in the Pacific Ocean off the coast of Oregon.

A variant of the initial IPS buoy concept, due to Stephen Salter, is the sloped IPS buoy: The natural frequency of the converter may be reduced and the capture width enlarged, if the buoy-tube set is made to oscillate at an angle intermediate between the heave and the surge directions. The sloped IPS buoy has been studied since the mid-1990s at the University of Edinburgh by model testing and numerical modelling (Salter and Lin, 1998; Payne et al., 2008a, b).

The theoretical dynamics of a 2-body heaving wave energy converter has been analysed in detail by Falnes (1999). See also Falnes (2002) and Falcão et al. (2008), where the concept of an equivalent 1-body oscillating system is introduced and discussed.

The theoretical modelling, in the frequency and time domains, of a simplified version of the IPS wave power buoy was developed by Falcão et al. (2008) and used for optimization of the geometry and of the PTO.

The utilization of genetic algorithms for WEC optimization was first used by Clément et al. (2005) for the 2-body wave energy converter SEAREV. Recently, McCabe et al. (2009) presented a study about the optimization with genetic algorithms of the shape of a WEC moving in surge and pitch.

In the modelling and geometry optimization of the IPS buoy presented here, a linear PTO was assumed (consisting of a linear damper and a linear spring), which allows a frequency-domain analysis to be adopted. A boundary-element code was used to compute the hydrodynamic coefficients. Computations with regular waves were performed first. Results for irregular waves with a given spectral distribution were obtained by linear superposition. The geometry optimization is carried out with the aid of genetic algorithms, using a criterion involving the absorbed energy and the structural volume of the device. Results are presented for a wave climate off the western coast of Portugal.

IPS WAVE POWER BUOY

The IPS buoy consists basically of a buoy rigidly connected to a submerged tube (the acceleration tube), oscillating in heave by the action of the waves, with respect to a piston that can slide along the tube. The wave energy is absorbed from the relative motion between the piston and the buoy-tube set. The concept is represented in Fig. 1. It should be noted that most of the inertia against which the buoy moves is that of the water contained inside the acceleration tube (obviously in addition to the mass of the piston itself). The IPS buoy has an axisymmetric geometry, with a cylindrical floater and an acceleration tube of uniform annular cross-section. (We do not consider any modification to the tube to avoid end-stop problems.) The mass and volume of the structure linking the floater and the tube are neglected, as well as the hydrodynamic forces on the structure. It is further assumed that the floater-tube system is constrained to oscillate in heave, which may

Received May 7, 2010; revised manuscript received by the editors August 9, 2010. The original version (prior to the final revised manuscript) was presented at the 20th International Offshore and Polar Engineering Conference (ISOPE-2010), Beijing, June 20–25, 2010.

KEY WORDS: Frequency domain, genetic algorithms, irregular waves, optimization, 2-body oscillating system, wave energy.