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Frequency Response Tuning for a Two-Body Heaving Wave Energy Converter

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ABSTRACT

This study investigates frequency response tuning for a two-body heaving wave energy converter. The wave energy converter presented is a scale model "spar-float" configuration to be tested at the National Research Council Institute for Ocean Technology, St. Johns, Newfoundland. The purpose of these tests is to validate a novel tuning mechanism which affords active adjustment of the spar natural frequency. In this work, a systematic optimization procedure is used to demonstrate the utility of this tuning mechanism. The spar geometry is parameterized so that the reference depth can be input to a simplified heaving dynamics model which utilizes the long-wavelength approximation. Closed form solutions to the linear heaving dynamics model are used to establish objective functions. For a range of wave frequencies corresponding to the wave tank capabilities, optimal natural frequencies for the spar are computed. The results show that an ability to vary the spar's natural heaving frequency is indeed beneficial, and that significant power absorption benefits can be attained at low wave frequencies using the suggested tuning mechanism to produce these frequency adjustments.

KEY WORDS: Wave energy conversion; point absorber; heaving buoy; parametric design; optimization; control system

INTRODUCTION

The concept of an internally housed, oscillating reaction mass for the purpose of frequency response tuning is not new. However, the suggested implementations to date require complex control schemes and/or energy intensive actuators. French and Bracewell developed a heaving point absorber with latching control of an internal reaction mass (Bracewell (1990)). Called "Frog," the device absorbs energy from the relative motion between the reaction mass and the hull, but latching control requires excellent knowledge of the wave regime on a prohibitively short time scale. Korde presents a tuning system that utilizes a ship heave compensator (Korde (1999)), similar to those typically used to minimize TLP motions (Alves and Batista (1999)), as a vibration absorber to maintain a fixed reference against which a heaving body can react. These systems require continuous operation of an actuator to provide frequency response adjustments. Avoiding such energy intensive control adjustments saves valuable converted electrical energy. A two-body heaving WEC that utilizes a novel frequency response tuning system is under development at the University of Victoria. The tuning system uses an internal reaction mass to generate the frequency response adjustments. Gerber (2007) describes a theoretical variable spring stiffness control over a fixed reaction mass. In contrast to that concept, the current work complements variable spring stiffness with inertial adjustments to affect changes in the frequency response of the spar. The adjustments are completed in a short time to capitalize on the predominant wave components and no energy is consumed between adjustments. In contrast to the methods of Bracewell (1990) and Korde (1999), the tuning system proposed in this work requires neither large control forces nor latching control to operate. In this work, the need for frequency response tuning is established using optimization methods to quantify ideal variations in the two-body WEC's spar frequency response. These variations are compared to those achievable using a novel electro-mechanical tuning mechanism.

This work follows the philosophy of Bjarte-Larsson and Falnes (2001): a simplified wave-body dynamics model is used to explore the potential benefits from, and justification of, this type of tuning system in a wave-tank specific design scenario. In addition, a methodology is developed for the synthesis of relative motion based heaving WEC designs. The first section establishes parametric design laws for the structure of the two-body WEC prototype. The second section describes the simplified wave-body dynamics model. In the third section, the model is then applied to investigate the frequency response behavior of the WEC with no generator. The fourth section builds on the previous section by applying a generator of optimal intensity. In the fifth section, a fixed spar shape is maintained while the frequency response is explored. Finally, in the last section, the novel frequency response tuning concept is introduced.

WEC STRUCTURE

Design Constraints

The most important parameter that drives the design of a heaving body is the natural frequency of the body $\omega_j = \sqrt{k_j/m_j}$. The hydrostatic stiffness of the body is proportional to the water plane area i.e. $k_j = \rho g \pi r_j^2$ and the mass of the body, by static force balance and Archimedes law, is proportional to the submerged volume i.e. $m_j = \rho V_j$. If the body