An Internally-Resonant Tunable Generator for Wave Energy Harvesting

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Abstract. This work exploits a two-to-one internal resonance energy pump to design a wave energy absorber with improved bandwidth capabilities. The proposed absorber consists of two coupled (primary and auxiliary) oscillators. The primary oscillator is a partially-submerged buoy whose stiffness results from the hydrostatic force. The auxiliary oscillator, which consists of a mass and a nonlinear spring, is mounted inside the buoy and has its frequency tuned to the dominant frequency in the sea wave spectrum and to half the natural frequency of the primary oscillator. When the buoy is subjected to the low-frequency wave excitations, the auxiliary oscillator resonates with the wave excitation and starts to move. Energy is then channeled to the primary oscillator through the two-to-one internal resonance energy pump. Experimental results performed using an electrodynamic shaker to simulate the sea waves demonstrate that the voltage output of the proposed absorber has a wider frequency bandwidth and is less sensitive to variations in the frequency of excitation.

Introduction

Point wave energy absorbers (PWAs) are considered to be the simplest, most efficient, and mostly widely-utilized approach to harness wave energy. They currently occupy 40% of the market share and are often preferred over other types because they can be scaled down without considerably reducing efficiency. However, PWAs suffer from a main shortcoming which limits their efficacy. This shortcoming emanates from their very fundamental principle of operation which is based on establishing resonance conditions between the sea waves and the absorber. This occurs when the natural frequency of the converter is close to one of the dominant frequencies in the wave energy spectrum. Establishment of resonance however leads to three main issues. i) Because of the high stiffness of the hydrostatic restoring force resulting from buoyancy, the natural frequency of the absorber is typically higher than that of the dominant frequencies in the wave energy spectrum. As a result, to reduce its natural frequency, the absorber has to be augmented with a heavy submerged body or other complex mechanical and control solutions. ii) Even when incorporating the proper design means to reduce the frequency of the PWA such that it matches the dominant frequencies in the spectrum of the incident waves, much of the available wave energy is still lost. This is because the resonant bandwidth of the PWA is much narrower than the spectrum of the incident waves whose energy is distributed over a wide range of frequencies. iii) Operating the absorber at the linear resonance can also sometimes lead to very large amplitude motions that adversely influence the structural integrity of the absorber.

To overcome the above mentioned issues, we propose a new design of PWAs that has i) a broader bandwidth and lesser sensitivity to variations in the excitation frequency, ii) can respond to excitation frequencies that are as low as half its fundamental frequency, and iii) does not exhibit the large-amplitude small-bandwidth resonance peak typical of the linear PWAs. The absorber consists of two coupled oscillators. The first, denoted here as the primary oscillator, comprises of a partially-submerged buoy of mass, m_1, and stiffness, k_1, resulting from the hydrostatic forces. The primary oscillator has a high natural frequency due to the high stiffness of the hydrostatic restoring force. The second oscillator, denoted here as the auxiliary oscillator, has a mass m_2, and a nonlinear stiffness created by magnetic levitation. The auxiliary oscillator is mounted inside the buoy with its natural frequency tuned to the dominant frequency in the wave spectrum and to half the natural frequency of the primary oscillator. When the buoy is subjected to the low-frequency wave excitations, the auxiliary oscillator resonates with the wave excitation and starts to move. Energy is then channeled to the primary oscillator due to the 2-to-1 internal resonance between the two oscillators. This results in a reasonably large-amplitude relative motion between the two oscillators over a wide spectrum of frequencies. This motion can then be channeled into electricity as per Faraday's law. Figure 1 depicts the experimentally-observed time history of the voltage response of the absorber for the 2-to-1 tuned frequencies as compared with the detuned case for both (a) forward and (b) backward experimental frequency sweeps as well as (c) a schematic for the system.

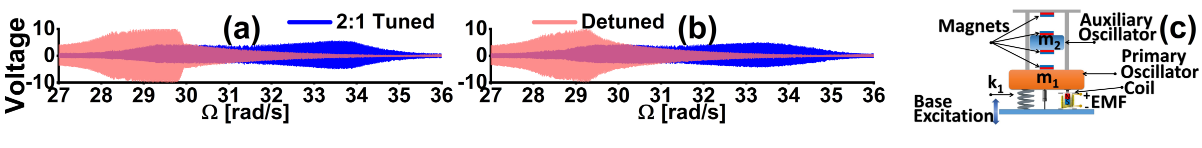

Figure 1: Comparison between experimentally-observed time history of the induced voltage.

References

[1] Engström, Jens, et al. (2009) Wave energy converter with enhanced amplitude response at frequencies coinciding with Swedish west coast sea states by use of a supplementary submerged body. *J. Applied Physics* **106(6):064512.**