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Synchronization control of parametric pendulums for wave energy extraction

A. Najdecka[1], V. Vaziri, M. Wiercigroch

[1]University of Aberdeen, Centre for Applied Dynamics Research, School of Engineering
AB24 3UE, Aberdeen, UK,
e-mail: r02ajn9@abdn.ac.uk

Abstract.

In this work the dynamics of a parametric pendulums system has been studied with a view to its application for sea wave's energy extraction. The idea is based on the conversion of the oscillatory motion of the waves into rotation of the pendulums. The system approximating a floating structure with two pendulums mounted on it has been modelled and analyzed. In the first stage of the study the general dynamics of the parametric pendulums has been investigated numerically and experimentally. The focus lies on synchronized rotational solutions, representing a most energetically favourable state of motion. The target state is to achieve a synchronized counter rotation of both pendulums. The controlling strategy, with the aim of initiating and maintaining the desired response, has been developed and verified numerically and experimentally. Different methods based on the delayed-feedback control have been suggested. The numerical and experimental results showing the difference in the system dynamics with and without control have been presented. Finally the energy extraction from the system has been simulated numerically and energy extraction control has been discussed.

Key words

Parametric pendulum, coupled pendulums, synchronization, delayed-feedback control, wave energy extraction

1. Introduction

The need to search for new alternative energy sources has been getting stronger in recent decades. The ocean waters despite being main solar energy collectors on earth, sill remain a highly unexplored energy source. Number of different technologies based on utilizing tides, oceans thermal energy and wave energy are being deployed however there is still need for further research in this area.

The motivation of this study is the idea of using the dynamics of the parametric pendulums for wave energy extraction. This concept has been proposed by Wiercigroch [1] and is based on the conversion of the kinetic energy of sea waves into rotational motion of the pendulum, mounted on the floating pontoon. The rotational motion of the single pendulum regarding this application has been studied in [2], [3]. The working principle of the parametric pendulum has been illustrated at the pictures below (Fig.1). The pivot point is subjected to harmonic excitation in vertical direction (Fig.1a). A parametric pendulum experiences different types of motion, which can be represented on the phase plane (Fig.1b). The region of oscillatory solutions (closed loops denoted by (1)) is bounded by a critical motion described by the separatrices (2). The response outside this region is denoted by (3) and corresponds to the rotation, which is of main interest for the energy extraction purposes. For stable rotations the solution on the phase plane needs to lie sufficiently far from the separatrix to ensure that the energy dissipation will not cause the pendulum to go back to the potential well inside the region bounded by separatrices. Once the pendulum rotates its energy can be extracted directly from the rotating shaft at the pivot point, which will be the scope of the following studies.

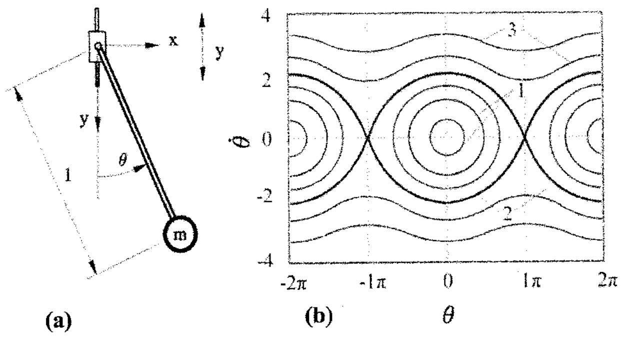

Fig.1 Working principle of parametrically-excited pendulum. Schematic representation (a) and phase plane showing different responses in terms of pendulum displacemnet and velocity (b).

A floating structure containing the pendulums system, would be subjected not only to the excitation originating from the sea waves but also reaction forces related to the rotating pendulum acting on the pontoon. The objective of this project is to design a structure which would utilize these interactions for increasing the stability of the pontoon and rotational motion, rather than suppressing them. It can be achieved by employing the set of