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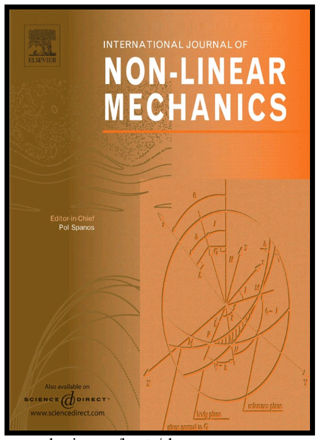

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Energy harvesting from pendulum oscillations

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Abstract

In this work we analyse the possibility of energy harvesting from the vibration of the environment. The investigations are performed using experimental rig, which consists of a parametrically forced pendulum and an energy harvester, and the mathematical model developed based on the experimental rig. Numerical studies focus on the oscillating motion of pendulum in 2 : 1 resonance and show good agreement with experimental results. We present that the energy harvesting is possible and is more efficient for shorter reduced length of the pendulum, as proved numerically and experimentally.

Keywords: energy harvesting, pendulum

1. Introduction

Pendulum is the most fundamental example of mechanical oscillator. It has drawn attention of scientists since ages, just to mention Galileo [1] or Huygens [2]. The basic application of pendulum is to measure the time, as for small swing amplitude φ_0 the period T depends only on the length of the pendulum l, which can be formulated as follows:

$$T = 2\pi\sqrt{\frac{l}{g}} \qquad \varphi_0 \ll 1. \tag{1}$$

The pendulum has a simple design principle, yet can exhibit very complex dynamics [3] and has been widely used as a building block in complex non-linear systems [4–13]. When the pendulum is subjected to excitation with angular frequency ω two times larger than the natural frequency Ω, a 2:1 parametric resonance occurs. Such a property of the pendulum has convinced scientists to investigate possible application of pendulum in energy harvesting. Most of the ideas involve using sea waves as source of excitation. The pendulum system, placed on floating structure, oscillates or rotates transforming mechanical energy into electrical energy [14, 15]. The topic of rotating solutions of parametrically excited pendulum is addressed in [16], while the optimization of energy extraction from such a system is presented in [17]. Energy extraction from rotary motion of pendulum subjected to stochastic wave excitation is described in [18]. Laboratory experiments in wave flume are performed in [19], as well as in [20] where authors test 1:45 scaled model of energy harvesting device, prepare simple analytical model and make usability study based on the oceanographic data for Italian coastline. However, when using sea waves as an excitation source for the pendulum system, one should construct long pendulum in order to obtain 2:1 resonance. For example a period of sea waves $T_w = 3$ [s] corresponds to almost nine meters long pendulum (according to [21] ordinary gravity waves periods span from 1 [s] to 30 [s]). The problem of obtaining low natural frequency of pendulum is addressed

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