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Assessment of energy harvesting and vibration mitigation of a pendulum dynamic absorber

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ABSTRACT

The paper presents a novel system for simultaneous energy harvesting and vibration mitigation. The system consists of two main parts: an autoparametric pendulum vibration absorber and an energy harvester device. The recovered energy is from oscillation of a levitating magnet in a coil. The energy harvesting system is mounted in a pendulum structure. The system allows energy recovery from a semi-trivial solution (pendulum in rest) or/and swinging of a pendulum. The influence of harvester parameters on the system response and energy harvesting in a parametric resonance is studied in detail. The harvester device does not decrease vibration reduction effectiveness.

1. Introduction

1.1. Vibration mitigation

Theory and methods of vibration control and mitigation in different engineering applications have been extensively studied for many years [1–7]. One of these methods is passive vibration mitigation based on a structural modification by adding a dissipative material, e.g. viscoelastic material [8] or dynamical vibration absorber (DVA) [9]. Dynamical vibration absorbers are configured and attached to a vibrating primary system to attenuate its undesirable forced dynamic response. This method is a very interesting and often used in practice due low cost (bridges, pylons of bridges, chimneys, TV towers, skyscrapers (Taipei 101)). Moreover, that their performance is acceptable without requiring external energy supply [10]. In the vibrations theory, the DVA is a system designed to mechanical vibration minimization or reduction, by the energy transfer from the primary system to the vibration absorbers (tuned mass damper). In practice, dynamic vibration absorbers can be included in the original system design or can be added to an existing system as separate subsystem. The tuned mass damper (TMD) is probably the most popular device for passive vibration mitigation of mechanical structures [11]. The classical TMD consists of a mass spring system, and it effectiveness is strongly limited to peak response. However, the nonlinear vibration absorbers are much effective in a larger frequency range due to the frequency – energy dependence of a nonlinear oscillations [12].

The one example of the nonlinear absorbers is an autoparametric vibration absorbers. Autoparametric systems are interesting vibrating systems, which consist of at least two nonlinearly coupled subsystems. The secondary subsystem is coupled

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to the primary subsystem nonlinearly, but in such a way that the secondary subsystem can be at rest while the primary one is vibrating. This is called a semi-trivial solution or normal mode [13,14]. Autoparametric vibrations (both subsystems oscillates) occur only in a limited region of the tuning parameters and such systems are sensitive to the system parameters and initial conditions [14].

1.2. Energy harvesting (EH)

Mechanical vibrations are more and more considered by many to be one of the most effective methods for implementing energy harvesting devices [15–20]. A practice examples of the EH could be bridges, tunnels or buildings where sensors are required to assess continually the vibration levels and the integrity of the structure whilst at the same time, being powered by those same vibrations, and transmitting data via wireless link for processing [21,22]. Energy harvesting is a process of transforming ambient vibrational kinetic energy into useful an electrical energy. The recovered energy from mechanical systems using sources such as vibration, mechanical stress and strain.

The most popular vibration method are: Variable Capacitance Systems, Piezoelectric Material Systems and Magnetic Induction Systems. The Variable Capacitance Systems energy harvesting transducers vibration energy through the electric fields between a parallel plate capacitor with movable plate. The magnitude of the recovered energy from such systems is generally on the order of microwatts [23]. The piezoelectric systems will produce an electric field and consequently a voltage when deformed under an applied stress. The magnitude of energy harvested from these systems can vary from microwatts to watts [24]. Similarly, to the piezoelectric are a magnetostrictive material will produce a magnetic field when deformed. The magnetic induction systems (also called electromagnetic systems) use the motion of a permanent magnet to induce a voltage across the terminals of a coil of wire. This motion causes the magnetic flux through the coil which leads the induction of voltage. This voltage is used to energize an electrical circuit. The magnitude of energy harvested from magnetic induction can range up to kilowatts, strongly depending on the size of the magnetic induction systems [25].

1.3. Motivation

The main motivation is a research project: "*Evaluation of an energy harvesting from a pendulum vibration absorber*" *realized at Lublin University of Technology*. Inspired by the idea of energy harvesting and vibration mitigation a new type of dynamic vibration absorber called harvester absorber system (HAS) is proposed. Introducing an energy harvester device to passive vibration absorber would be of interest for the purposes of enhancing its control effects and use to power recovery [26,27]. However, the adding harvester device to the dynamical vibration system can change dynamics by introduce new stable/unstable solutions.

This paper presents numerical and experimental analysis of the HAS. It is dedicated to vibration mitigation and energy recovery at the same time. The influence of the harvester parameters on vibration mitigation and harvested energy is studied is detail.

2. Harvester-absorber system

In this section the laboratory rig dedicated for simultaneously energy harvesting and vibration mitigation has been presented.

2.1. Laboratory rig

The laboratory rig consists of two main components. The first is the pendulum (tuned mass damper) attached to the oscillator (main system). Both systems are inertial coupled and called autoparametric. The photo of the experimental system in Fig. 1(a) is shown.

The oscillator is periodically excited by a motor and the mechanism which changing rotational motion into translation. The second system is the harvester device which is mounted inside the pendulum structure, Fig. 1(b). The swinging of the pendulum causes vibration reduction of the main system and simultaneously energy recovery from the magnet oscillation in the pendulum's tube. Of course, the energy is recovered for the fixed pendulum, also. The system can have different type of motion: periodic, rotation, quasi-periodic or chaotic. The harvester device should be properly designed and tuned, then the vibrations effectiveness is not reduced. The nonlinear response gives the possibility of broadening the excitation frequency region over which energy can be harvested and the dynamics of the system can be controlled. The system is very complicated, has a three mechanical and one electrical degrees of freedom. The detailed description of the maglev device in next section is presented.

2.2. Maglev harvester

The concept of a maglev harvester device based on an electro-magnetic induction phenomenon. The maglev harvester device consists of the levitating circular permanent magnet in the coil. The magnetic levitation (maglev) effect is caused