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Application of nonlinear magnetic vibro-impact vibration suppressor and energy harvester

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ABSTRACT

In the present study, application of a single unit vibro-impact system is improved. For this reason, in the so-called "magnetic impact damper" the impact mass is replaced by a permanent magnet, which moves in coil of gap enclosure. In the magnetic impact damper, wasting energy during inelastic contacts of masses and converting energy into electrical energy during the mass movement inside the coil, leads to suppress undesired vibrations. In this study it is shown that the magnetic impact dampers are not only good vibration suppressors but also they can harvest electrical energy. Effect of changing the main parameters of this system including gap size, load resistance and electromagnetic coupling coefficient is studied on the vibratory and energy behavior of the magnetic impact dampers. Finally using several user oriented charts, it is shown that energy-based and vibration-based design considerations can effectively improve application of the discussed vibro-impact system.

1. Introduction

Nowadays, modern technology of silicon electronics reduced the power consumption of electronic devices [1,2]. For this reason, generating power by microscale systems, which can be used to harvest energy of environment vibrations, is extensively considered [3–5]. The reason for this interest lies in the fact that designing self-powered systems to eliminate the need to external energy sources, is not escapable. It should be noted that the vibration powered energy harvesters can be used for applications in systems such micro electromechanical actuators, implantable technologies, mobile electronics, wireless sensors.

In common application an electromagnetic vibration powered energy harvester is a simple vibratory system, which is designed such that the external excitation leads to coil and magnet oscillate with respect to each other. Then the time varying magnetic flux in the coil leads to induce an electric potential and while an electrical load resistance is attached to circuit, electrical current flows and electrical power will be delivered [6]. Using this concept, several studies have been done to develop various models for understanding the dynamic behavior of the energy harvesting systems and optimizing their designs. In doing so, the dynamic response and the electrical current are obtained by solving the governing differential equations.

Harvesting mechanical energy through converting wasted kinetic energy of vibration to useful electrical energy can be achieved by piezoelectric, electrostatic or electromagnetic transduction mechanisms [7–9]. The piezoelectric devices are most suitable for wireless sensors and MEMS devices, because they can be used over a wide range of frequencies and they

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can be made and placed in small volumes [10]. In this area of research, flexible beam, which can be equipped with piezoelectric patches, are often considered by researchers. Friswell et al. proposed an energy harvester system consists of a flexible beam with tip mass, which can work with low frequency and high displacement excitation [11]. Litak et al. studied energy harvesting using a composite beam with an additional moving mass, which is equipped with a piezoelectric patch [12]. In case of electrostatic systems, although size reduction leads to increase in capacitance of the device, but needing to control the dimensions in micrometer scale is where the problem lies [7]. The electromagnetic energy harvesters can be extremely efficient converters of kinetic energy into electrical but attempts to miniaturize, invariably reduces efficiency levels [2]. Furthermore, the output current of electromagnetic devices can be high and they are robust systems [7]. In past recent years, the electromagnetic devices have received interest in energy harvesting from vibrations. Jung and Lee experimentally studied the idea of energy harvesting from wake galloping, using electromagnetic systems [9]. Dai et al. modeled a galloping-based electromagnetic energy harvester and showed that to maximize the harvested power, an optimum value of the electrical load resistance can be determined [13]. Asai et al. introduced a mechanism named ″tuned inertial mass electromagnetic transducer″ for absorbing vibratory energy and harvesting energy [14]. Mann and Sims designed an energy harvesting device, which uses a floating permanent magnet between two magnets in a tube. They showed this system can largely oscillate over a wide range of frequencies and it can improve ability of energy harvesting [15]. Kucab et al. studied linear and nonlinear behavior of an energy harvester, which is consisted of a magnet travels in a tube surrounded by coil [16].

The energy harvesters are generally studied as a main system, which only generate energy. Whereas the main duties of the practical system may not be energy harvesting. It is more practical to study an energy harvester as a subsystem in a mechanical system, which does own duty except for energy harvesting. For this reason, this question may be posed that: “what is the effect of using the energy harvesters on the main application of the practical systems?”.

In the present study, application of an inner mass single unit impact damper, or simply “impact damper” as a vibration suppressor and an energy harvester is studied. An impact damper is a small loose mass, which can move freely in an enclosure connected to a main vibratory mass. When the vibration amplitude of the main mass exceeds than the gap size, the impact mass collides with main mass barriers. Consequently, the kinetic energy of the main mass is absorbed and converted to heat and sound through inelastic collisions [17,18]. These systems can be extensively applied to attenuate the undesirable vibration of robot arms, turbine blades and so on and behavior of this system has been investigated experimentally, analytically and numerically [19,20]. The main target of the present study is to analyze the free vibration of a vibratory system, which is equipped with a vibro-impact system, which is simply named as “magnetic impact damper”. In the so called magnetic impact damper, a coil is wounded around the enclosure of the impact damper and a permanent magnet is selected as the impact mass. These changes, causes some of useless kinetic energy of masses converted to useful electrical energy. Furthermore, effect of changing the load resistance and electro-mechanical coupling coefficient on the vibration and energy behavior of the magnetic impact damper is studied.

2. Mathematical modeling

2.1. Mathematical model of the main system

To study free vibration of a system equipped with the magnetic impact damper, a fixed-guided beam, with tip mass, equipped with the magnetic impact damper with the impact mass m and gap distance d, as shown in part (A) of Fig. 1, is

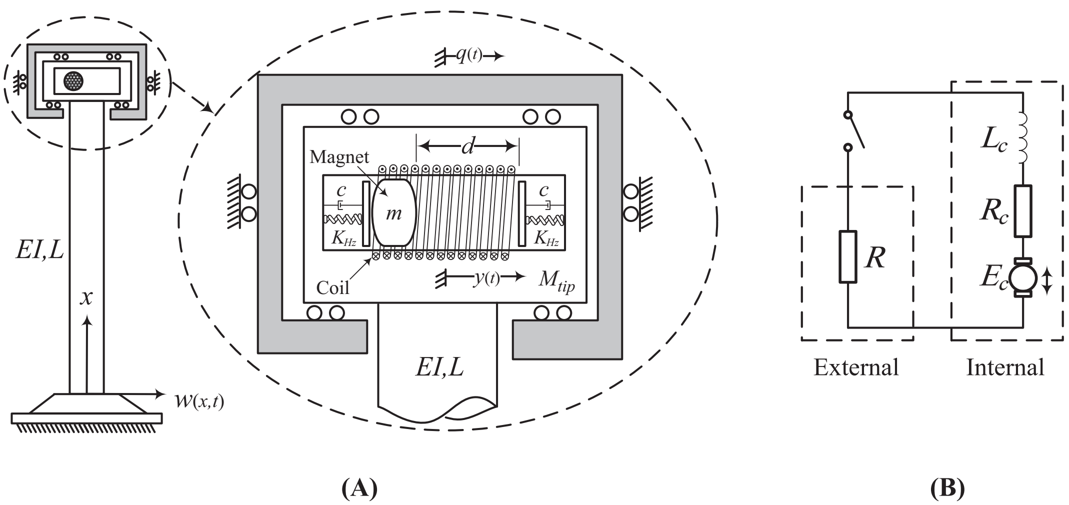

Fig. 1. Schematic of the magnetic impact damper (A); equivalent circuit of the coil (B).