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Dynamics of Energy Harvesting Mechanical System in the Vicinity of 1:1 Resonance,

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Abstract: Energy harvesting provides a useful way to power electronic devices without using batteries or electrical wiring. Energy harvesting can be defined as the conversion of environmental energy, such as mechanical, thermal, light energies into usable electrical energy. Conventional mechanical energy harvesting devices use a line harvester to generate electricity through vibrations or other mechanical motion. However, linear generators generate significant power in a narrow band around resonance, and the power is limited by the internal damping factor and the driving force at the resonant frequency. Such devices implementing a linear (resonant) generator cannot generate sufficient specific power. In present paper the mechanical system is considered which consists of two coupled oscillators (nonlinear absorber connected with primary mass) and a piezoelectric element attached. Two goals are pursued: the mitigation of the responses of the main mass and maximizing the amount of energy extracted from vibrations. The influence of nonlinear stiffness's component is discussed. It is shown that the piezoelectric element allows the effective energy harvesting and at the same has very limited influence on reducing the amplitude of oscillations of the main mass.

Keywords: electro-mechanical system, nonlinear absorber, external excitation.

1. Introduction

The energy harvesting in recent years has attracted increased attention from various disciplines [1-5], mainly due to its potential to act as a key technology that allows the creation of ultra-low-power electronic systems with autonomous power. Kinetic energy harvesters, also known as vibration power generators, are typically the inertial spring-mass systems. Electrical power is extracted by employing one or a combination of several transduction mechanisms. Normally, the transduction mechanisms are piezoelectric, electromagnetic or electrostatic. As most vibration power generators are resonant systems, they generate the maximum power in the vicinity of the resonant frequency. The piezoelectric energy harvesting remains one of the most widely researched harvesting method due to its ease of application and relatively high voltage output. In this report, an energy harvesting device based on a dynamic vibration absorber is studied to achieve two objectives: vibration suppression and energy harvesting in a wideband range. Models using various types of oscillations were considered by many researchers [6 - 8]. Among models considered are: a cantilever beam carrying a tip mass [9], tuned auxiliary structure [10], rotational motion system [11].

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2. Results and Discussion

Consider a harmonically excited linear oscillator (primary system) coupled with a nonlinear absorber (secondary system or NDVA). The primary structure is assumed to be a single degree of freedom system which mass and stiffness are represented by m_0 and k_0, respectively, whereas the corresponding notions for the energy harvesting DVA are m_a and k_a, respectively, and c_a – damping coefficient. The electrical capacitance and resistance are denoted by C_p and R_l, respectively. The parameter θ characterizing the coupling between the electrical and mechanical parts of the harvester. The dynamics of the system can be expressed by three coupled ordinary differential equations in the following form

$$m_0\ddot{x}_0 - c_a(\dot{x}_a - \dot{x}_0)+k_0x_0 - k_a^{lin}(x_a - x_0)+k_a^{nonlin}(x_a - x_0)^3=F_0\cos\omega t, \tag{1}$$

$$m_a\ddot{x}_a+c_a(\dot{x}_a - \dot{x}_0)+k_a^{lin}(x_a - x_0) - k_a^{nonlin}(x_a - x_0)^3- \theta v = 0, \tag{2}$$

$$\theta\,\dot{x}_a+ C_p\dot{v}+v/R_l = 0. \tag{3}$$

where x_0 and x_a are the displacement of the primary mass and absorber mass, respectively. The voltage across the load resistor is denoted by v.

The aim is to determine the parameters of the absorber and the piezoelectric element in such a way as, on the one hand, to ensure that the responses of the main system are minimized in the vicinity of the resonance, and on the other hand, to maximize the collection of energy. Generally speaking, the goals set are contradictory, so the task is to find some compromise. In this paper, we first establish acceptable limits for the system parameters, which guarantee a predetermined upper limit on the amplitude of the oscillation of the host system. Having thus obtained a certain region in the parameter space, we solve the second part of the problem to get the maximum benefit for the function V^2/R_l.

3. Concluding Remarks

An electro-mechanical system consisting of a primary element, a dynamic absorber and a piezoelectric element is considered. The goal is to reduce the vibration of the primary structure and at the same time collect the energy through the interaction of the host system and the vibration absorber. An analytical and numerical study of the dynamics of the system is carried out.

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