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A vibro-impact oscillator based energy harvester

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Abstract A piezoelectric energy harvesting system based on vibro-impact is investigated in the present study. The harvesting configuration comprises a primary unimorph beam which undergoes impact with two other unimorph beams on its either side. The governing equations of the piecewise-smooth linear dynamical system are developed using Hamilton's principle of least action. The dynamics and harvesting performance of the system under study are characterized through numerical simulations. The effect of parameters such as the clearance between the harvesters, frequency and amplitude of excitation on the magnitude of power and bandwidth are discussed in this study.

Keywords: vibro-impact, unimorph, energy harvesting, piezoelectric

1. Introduction

Wireless sensor systems are highly desirable in areas such as structural health monitoring as they reduce the maintenance requirements and this can only be accomplished by using batteries and/or harvested energy. Several works in the literature demonstrate that the power density obtained through piezoelectric vibration energy harvesters are comparable to thermoelectric generators and lithium-ion batteries. The common configuration of piezoelectric cantilever with a tip mass works well for harmonic excitation and exploits the linear resonance of the system [1]. Vibro-impacts are known to be a source of high kinetic energy. Recently, few of the works on energy harvesting have briefly outlined the importance of vibro-impacts in improving the power output [2]. Along these lines, a new harvesting system undergoing vibro-impacts is studied in this paper for its role in harnessing sizeable magnitude of power.

2. Harvester model and solution

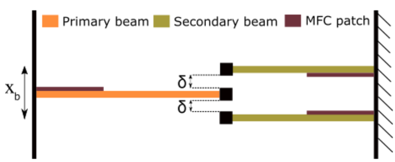
The configuration of the system is inspired from the work done by Krishna and Padmanabhan [3] on investigation of second mode response of impacting cantilever beam and is shown in Fig. 1(a). The system includes a primary cantilevered unimorph in the middle separated from the secondary cantilevered unimorphs by a clearance. The mathematical model of the system is derived based on Euler Bernoulli's assumptions. Euler-Lagrange method is used to develop the governing electromechanical equations of the system. Since there is a time dependent contact between the unimorphs during vibro-impacts, the system is idealised as piecewise-smooth linear oscillators. The primary unimorph is given a harmonic base excitation, which is then transferred to the secondary unimorphs due to vibro-impacts. The governing equations the system are given by,

$$M\ddot{x} + C\dot{x} + Kx - \theta v = F$$
$$C_p \dot{v} + \frac{v}{R_l} + (\theta)^T \dot{x} = 0 \qquad (1)$$

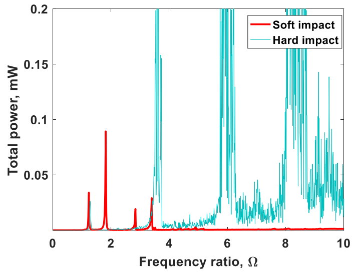
where M is the mass matrix, C is the damping matrix, K is the stiffness matrix, θ is coupling coefficient vector, x is the displacement vector, F is the vector of forces due to base displacement and v is the voltage vector. The stiffness matrix includes the terms accounted for both the stiffness of the system as well as the contact stiffness arising during impacts. The solutions of the governing equations are obtained through numerical simulations.

3. Results and Discussion

The natural frequencies of the primary (10.42 Hz) and secondary beams (14.75 Hz) are kept to be constant for all the studies carried out in this work. The effect of two different types of impacts namely the soft and hard impacts (classified depending upon the magnitude of contact stiffness relative to the stiffness of beams) for a given amplitude of excitation (2 mm) and clearance (1.2 mm) on the total power output are captured in the frequency responses shown in Fig 1(b). The magnitude of power harvested during hard impacts is observed to be significantly higher than during soft impacts. Hard impacts are also observed to enable the harvester to operate over a broader bandwidth as opposed to soft impacts. Time series analysis conducted in the study also showed that hard impacts predominantly involve chaotic responses than the soft impacts the effect of which on the magnitude of power averaged over time has been discussed in this work. Parametric studies are also conducted to study the influence of bifurcations arising due to the variation of amplitudes of excitation and clearance on the total output power.



(a)



(b)

Fig. 1. (a) Schematic representation of the harvesting system (a) Frequency response of total power during soft and hard impacts

4. Concluding Remarks

The present study explores the possibility of exploiting vibro-impacts for improving the power output of a piezoelectric energy harvesting system. Results presented in the study show that vibro-impacts positively influence the magnitude and bandwidth of the harvested power for a given set of system parameters. The operating parametric regimes for enhanced energy harvesting are also identified from the bifurcation plots presented in the study.

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