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Nonlinear Dynamics of Axially Loaded Piezoelectric Energy Harvester

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Abstract

In the present work nonlinear dynamics of axially loaded energy harvester which is modeled as a fixed-guided beam with tip mass having piezoelectric patch has been investigated. The system is subjected to a base excitation and periodic axial load. The governing equation of motion of the system is developed using Lagrange principle. A closed form solution has been developed to find out the response and generated voltage using method of multiple scales (MMS). Frequency response of the system is obtained for superharmonic and subharmonic resonance conditions and parametric study has been carried out in order to investigate the variation of output voltage with different system parameters.

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Keywords: Nonlinear dynamics; piezoelectric energy harvester; periodic axial load; Method of multiple scales.

1. Introduction

To make devices smart, self sufficient and battery less, available ambient energy can be utilized to power such devices by using embedded smart materials [1]. One such ambient energy is vibration energy. Resonance plays dominant role in case of energy harvesters based on vibration energy. In case of energy harvesters based on linear vibration, only primary resonance with short frequency bandwidth is available for energy conversion [2,3]. In order to extract vibration energy over a wide range of frequency bandwidth there has been attempt made by researchers to exploit the nonlinear behavior of vibration [4-6, 11]. Nonlinear dynamics of axially loaded beam structure as an energy harvester [4] and as a manipulator [12] have been investigated by few researchers. By considering the fact

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that apart from primary resonance the phenomenon of secondary resonance conditions exists in systems having nonlinear vibrations may help to enhance the performance of energy harvester over wide range of excitation frequencies.

In the present work a fixed-guided beam based energy harvester embedded with piezoelectric patch is proposed. The harvester is having tip mass at its guided end. It is subjected to harmonic base and axial excitation as shown in Fig. 1. Euler-Bernoulli beam theory is applied for slender fixed-guided beam. The governing equations of motion of the system have been derived using Lagrange and Galerkin's principles. Nonlinear governing temporal equation of motion is solved using the method of multiple scales.

2. Modelling

The proposed energy harvester consists of a uniform inverted fixed-guided beam of length L_s, tip mass M_t with piezoelectric patches of thickness h_p, width b_p and length L_p. It is subjected to a harmonic base excitation and an axial load at its guided end as shown in Fig. (1). The top end of beam is constrained to move in axial direction where tip mass is placed. Lagrange principle is used to derive the governing equations of motion and Galerkin's method is used to discretize the space-time domain. The study is limited to the pre-buckling regime only.

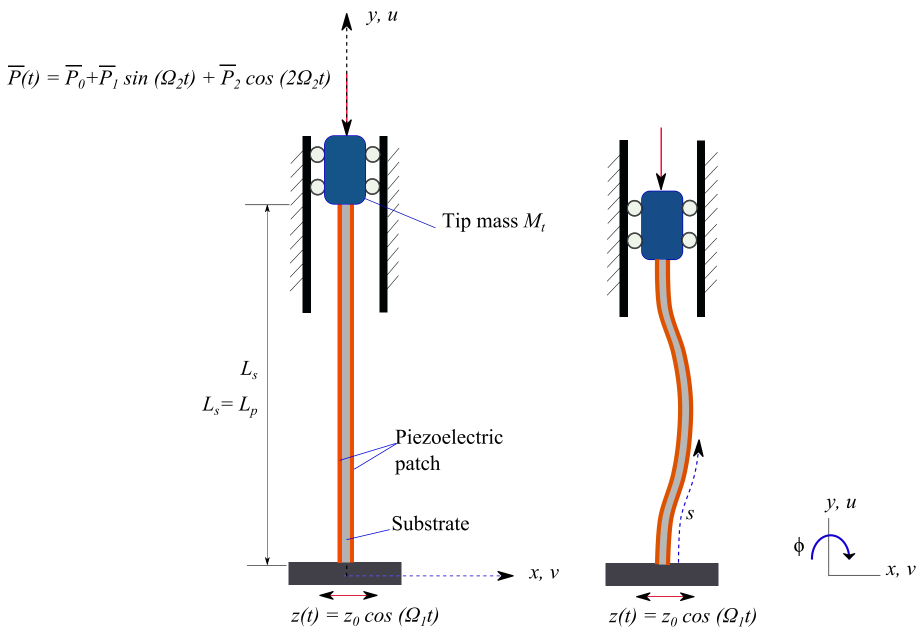

Fig. 1. Axially loaded inverted fixed-guided beam configuration with tip mass, harmonic base excitation and piezoelectric patches

2.1. Governing equation of motion

The Kinetic energy T and the potential energy U of the system in terms of curvature $k(s,t)$ and displacements u and v can be expressed as [5]

$$T = \frac{1}{2}\rho A\int_0^L \left\{ \left(\dot{v}(s,t)\right)^2 + \left(\dot{u}(s,t)\right)^2 \right\} ds + \frac{1}{2}M_t \left\{ \dot{u}^2(L,t) \right\} \tag{1}$$

$$U = \frac{1}{2}EI\int_0^L \left(k(s,t)\right)^2 ds - \rho A g \int_0^L u(s,t) ds - M_t g\, u(L,t) \tag{2}$$