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Wave propagation analysis of a functionally graded magneto-electro-elastic nanobeam rest on Visco-Pasternak foundation

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ABSTRACT

Wave propagation analysis of a nanobeam made of functionally graded magneto-electro-elastic materials with rectangular cross section rest on Visco-Pasternak foundation is studied in this paper. For modeling the axial, rotation and transverse deformations, Timoshenko beam model is used. Fundamental magneto-electro-elastic equations of the model are derived for a general functionally graded beam excited to electric and magnetic potentials. Surface elasticity is employed for more confident modeling the behavior of nanobeam. Using Hamilton principle and calculation of kinetic and strain energies, the equations of motion are derived. Considering the harmonic wave propagation of infinite domain yields characteristic equation of the system in terms of different parameters of model. The effects of different parameters such as non-homogeneous index, wave number and residual surface stress are investigated on the different phase velocities corresponding to modes of deformation. One can find that increasing the non-homogeneous index and wave number leads to decrease in wave propagation phase velocities.

1. Introduction

Considering the materials in very small scales reflects different behaviors in systems that were used structures in that scales. In traditional theory of continuum mechanics, no effect of sub materials in micro or nano scale was considered. To capture the effect of this significant parameter on the different behaviors of structures, a nonlocal model based on the Eringens theory of nonlocal continuum mechanics has been proposed for accounting the size dependency in very small structures [1]. After this novel issue, researchers have focused on different analysis of structures in nano and micro scales. The literature review indicates that wave propagation in structures in nano scale has significant applications as well as vibration, buckling and bending analysis of nano structures. A comprehensive literature review can justify necessity of current issue.

Yoon et al. [2] studied the effects of rotary inertia and shear deformation on the transverse wave propagation of carbon nanotubes (CNTs) based on Timoshenko and Euler beam models. Free vibration analysis of two-dimensional magneto-electro-elastic laminates including piezoelectric or magnetostrictive layers was studied by Ramirez et al. [3]. They used Ritz method to derive solutions for elastic displacements, electric and magnetic potentials. The obtained results have been compared with corresponding literatures based on analytical solutions and finite element approach. Wang et al. [4] employed nonlocal elastic continuous models to investigate transverse wave propagation in double-walled carbon nanotubes (DWNTs) based on the Euler–Bernoulli and Timoshenko beam models. Small scale effect was investigated on the wave dispersion of DWNTs. Chen et al. [5] presented magneto-electro-elastic wave propagation in multilayered plates with general anisotropic and three-phase coupled constitutive equations.

Wang et al. [6] presented free vibration analysis of a micro/nanobeam using Timoshenko beam model based on the Eringen's nonlocal elasticity theory. Hamilton's principle was used for derivation of governing equations and the results were presented for various end supports. The effect of small scale effect parameter was studied on the results. Heireche et al. [7] employed the Bernoulli–Euler and

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Timoshenko beam theories for a single-elastic beam model using nonlocal elasticity to develop wave propagation analysis in carbon nanotubes (CNTs). The small-scale effect was taken into account to study the wave propagation. Wang et al. [8] evaluated the group velocities of longitudinal and flexural wave propagations in single and multi-walled carbon nanotubes. They used a beam and a cylindrical shell model to express the dispersion relations between the group velocity and the wave number for flexural and longitudinal waves. Wave propagation responses of a FG magneto electro elastic plate were studied by Bin et al. [9]. The material properties ware assumed variable along the thickness direction. The effect of wave number has been studied on the Electric potential and magnetic potential distributions. Propagation of circumferential harmonic waves in piezoelectric-piezomagnetic FG cylindrical curved plates has been studied by Jiangong and Bin [10] based on Legendre orthogonal polynomial series expansion approach. The influences of piezoelectric and piezomagnetic effects have been studied on the dispersion curves of structures.

Murmu and Pradhan [11] studied the small-size effects in single-walled carbon nanotubes (SWCNTs). They used nonlocal elasticity and Timoshenko beam theory to investigate the stability response of SWCNT embedded in an elastic medium. The effect of different parameters such as nonlocal parameter, Winkler modulus parameter, Pasternak shear modulus and aspect ratio of the SWCNT was studied on the critical buckling loads. Wang [12] developed nonlocal Euler–Bernoulli elastic beam model for the vibration and instability of tubular micro- and nano-beams. The structure was conveying internal fluid. Using the nonlocal elasticity theory, the governing equations were derived. Narendar and Gopalakrishnan [13] studied the effect of nonlocal scale parameter on the wave propagation in multi-walled carbon nanotubes (MWCNTs). Wang et al. [14] investigated the effect of small scale effect on the longitudinal wave propagation of nanoplates. The equation of the longitudinal wave was obtained using the nonlocal elastic theory. The effect of wave number and small scale parameter was studied on the wave propagation velocities of the nanoplate.

Asghari et al. [15] implemented non-classical continuum theory to study nonlinear size-dependent Timoshenko beam model based on the modified couple stress theory. The results were derived for a hinged–hinged beam. Nonlinear free vibration of single-walled carbon nanotubes (SWCNTs) was studied by Yang et al. [16] using nonlinear strains Eringen's nonlocal elasticity theory. Using Hamilton's principle, both governing equations of motions and required boundary conditions of the system were derived. Vibration analysis of nano Timoshenko beams using nonlocal elasticity formulation was studied by Mohammadi and Ghannadpour [17] using an efficient numerical method based on Chebyshev polynomial functions. Static and free vibration analysis of a carbon nanowire with rectangular cross section was studied by Janghorban [18] using differential quadrature method based on the Timoshenko beam model. Asghari et al. [19] presented a size-dependent formulation for Timoshenko FG beam using modified couple stress theory to consider the small scale effects. The results indicated that modeling beams on the basis of the couple stress theory causes more stiffness than modeling based on the classical continuum theory. Ansari et al. [20] implemented vibration characteristics of microbeams made of functionally graded materials (FGMs) based on the strain gradient Timoshenko beam theory.

Strain gradient theory employed for wave propagation analysis of Euler-Bernoulli and Timoshenko beam models by Wang et al. [21]. The results presented for different small scale parameters. Wave propagation of micro/nanobeams using strain gradient elasticity based on the Bernoulli–Euler beam and Timoshenko beam models studied by Wang et al. [22]. The results indicated that increasing the wave number increases the angular frequency, phase velocity and group velocity of nano beam.

Ghorbanpour Arani et al. [23] studied wave propagation of a piezoelectric nanobeam as an element in micro or nano electromechanical systems using Euler–Bernoulli beam model and nonlocal elasticity. Two piezoelectric nanobeam was coupled by Pasternak foundation. Some important results such as in-phase and out-of-phase wave propagation characteristics and the effect of applied voltage were investigated. Magneto-electro-elastic analysis of nanoplates with simply supported boundary conditions using nonlocal theory based on Kirchhoff plate theory was studied by Ke et al. [24]. The influence of applied electric and magnetic potentials as well as nonlocal parameter on the vibration characteristics of nanoplates has been investigated. They concluded that applied electric and magnetic potentials have considerable effects on the responses, while the effect of thermal loadings can be ignored. Ke et al. [25] employed the nonlocal Love's shell theory to investigate magneto-electro-elastic free vibration analysis of cylindrical nanoshell rest on elastic foundation. The free vibration analysis of a doubly-curved thin shell rest on Pasternak foundation was studied by Razavi and Shooshtari [26] based on Donnell theory. The effect of two parameters of foundation and geometries of shell has been studied on the responses of the curved shell.

Shooshtari and Razavi [27] investigated nonlinear magneto-electro-elastic free and forced vibration analysis of rectangular thin plate with simply-supported boundary conditions using Von-Karman's nonlinear strains. They used Galerkin and perturbation methods to derive frequency response and nonlinear frequency of the magneto-electro-elastic plate. Magneto-electro-thermo-elastic analysis of a nano beam based on nonlinear geometric strains subjected to applied electric and magnetic potentials was studied by Ansari et al. [28]. Furthermore, they studied the effect of size dependency on the nonlinear forced vibration responses of nanobeams. Ansari et al. [29] have employed third-order shear deformable beam theory to study the magneto-electro-thermo-elastic analysis of nanobeams using nonlocal elasticity theory and nonlinear strain components. They performed a comprehensive investigation to present the effect of some important parameters such as nonlocal parameter, applied electric and magnetic potentials and geometric parameters on the nonlinear vibration responses of the system. Razavi and Shooshtari [30] studied nonlinear free vibration analysis of magneto-electro-elastic laminated rectangular plates with simply supported boundary conditions using first order shear deformation theory based on von Karman's nonlinear strains and Maxwell equations. The Galerkin method has been used to convert nonlinear partial differential equations of motion to couple nonlinear ordinary differential equations.

This paper is employed Timoshenko beam model for a functionally graded magneto-electric nanobeams rest on Visco-Pasternak foundation. All material properties are graded along the thickness direction of rectangular cross section of beam. The effect of material non homogeneities and wave number as well as nonlocal parameters of material is studied on the wave propagation of the nano-beam in different modes.