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Dynamic stability of single-walled carbon nanotube embedded in a viscoelastic medium under the influence of the axially harmonic load

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Abstract: The nonlinear model of a single-walled carbon nanotube (SWCNT) modeled as a nanobeam embedded in a Kelvin-Voigt viscoelastic medium is developed by using the nonlocal continuum theory. It is assumed that the nanobeam vibrates under the influence of the longitudinal magnetic field and time-varying axial load. Based on the nonlocal Euler-Bernoulli beam theory, Maxwell's equations and von Karman nonlinear strain-displacements relation, we obtain the nonlinear partial differential equations of transversal motion of the embedded nanobeam with different boundary conditions. The relationship between nonlinear amplitude and frequency of variable axial load in the presence of the longitudinal magnetic field is derived by using the perturbation method of multiple scales. An approximate analytical solution for nonlinear frequency and instability regions for the linear case of vibration is also considered in this paper. In order to analyze nonlinear dynamical stability regions of SWCNT, the incremental harmonic balance (IHB) method is introduced for obtaining iterative relationship of frequency and amplitude of time-varying axial load. It is showed that the nonlocal parameter, magnetic field effects and stiffness coefficient of the viscoelastic medium have significant effects on vibration and stability behavior of nanobeam and therefore receive substantial attention. In addition, from the presented numerical results one can see the influence of the small scale, magnetic field and foundation coefficients on the frequency-response curve, nonlinear frequency and instability regions for the linear and nonlinear cases.

Keywords: nonlocal elasticity; dynamic stability; embedded nanobeam; magnetic field; time-varying axial load;

1. Introduction

In the past few decades a great progress can be observed in the production process and application of nanoelectromechanical (NEMS) [1] systems and devices based on smart materials such as carbon nanotubes (CNT) [2 - 5], zinc-oxide (ZnO) [6 - 8], boron nitride nanotube [9, 10], graphene sheet [11, 12], gold nanoplates [13, 14] and so on. Due to their superior characteristics at the nano-scale these smart materials are potentially appropriate for many applications in various devices such as field emitters [15], nano-actuators [16], bio-sensors [17], mass sensors [18], drug delivery systems [19], as well as in the reinforcement of the nano-composite structures [20]. The special attention of scientist and engineers in this field is dedicated to the study of carbon nanotubes which possess extraordinary mechanical properties such as the high stiffness-to-weight and strength-to-weight ratio [21]. Therefore, analyzing and understanding the mechanical behavior of the CNT is a key step in the design of nano-devices based on them. In the nano-engineering practice there are three approaches which are usually applied to the study of the dynamic behavior of a nanotube: Experimental methods [22], Molecular Dynamic (MD) simulation [23] and continuum approach [24, 25]. Since performance and control experiments at the nano-level scale are a very expensive and difficult task, scientists and engineers direct their attention to the development of theoretical models based on the other two approaches. Various MD simulations based on deterministic or stochastic models are important in the analysis of the dynamic behavior of nano-systems with a small number of particles. In order to investigate the mechanical behavior of a complex nano-system, composed of a large number of particles, MD simulations are not suitable because they require substantial computer resources and are time-consuming. Therefore, continuum theory has become more important in modeling the dynamics of complex nano-systems based on the CNTs. On the basis of the atomic theory of lattices and some experimental observation, Eringen and co-workers [26-28] have extended the classical continuum theory with effects of long-range inter-atomic interaction in the form of a material parameter on the nonlocal continuum theory. The main assumption in this theory is that the stress at a point is a function of the strains at all points of the considered elastic body, which is of great importance in considering the effects on the nano-scale. By reviewing the literature one can find that the nonlocal theory is widely used for

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