Applied Mathematical Modelling 37 (2013) 6940–6951

Contents lists available at SciVerse ScienceDirect

Applied Mathematical Modelling

journal homepage: www.elsevier.com/locate/apm

Vibration of a single-walled carbon nanotube embedded in an elastic medium under a moving internal nanoparticle

Zhang Hong [a], Deng Qing-tian [a,*], Li Shao-hua [b]

[a] School of Science, Chang'an University, Xi'an 710064, China
[b] School of Science, Xi'an University of Science and Technology, Xi'an 710054, China

ARTICLE INFO

Article history:
Received 29 January 2012
Received in revised form 10 November 2012
Accepted 18 February 2013
Available online 27 February 2013

Keywords:
Vibration
Carbon nanotube
Nanoparticle
Elastic medium
Newmark method

ABSTRACT

Vibration of single-walled carbon nanotube embedded in an elastic medium under excitation of a moving nanoparticle is analyzed in this paper. Based on the Winkler spring model and the Euler–Bernoulli beam model, the time-domain responses of the single-walled carbon nanotube subjected to the moving transverse load with three different boundary conditions are computed by using the Newmark method. The effects of velocity and the excitation frequency of the moving internal nanoparticle and boundary conditions on the dynamic deflections of the single-walled carbon nanotube are discussed.

1. Introduction

In the last decades, nanoscale science and technology have been considering one of the most promising new directions of modern research, which may involve the ability to fabricate, characterize and manipulate artificial structures at the nanometer level. The motion of neutral atoms and nanoparticles inside nanotubes has been of considerable interest in view of the rapid progress of nanotechnology, and CNTs have been used as molecular channels for the drug delivery systems and the transportation of nanoparticles. In these applications, CNTs may suffer a transverse and longitudinal vibration process under the excitation of a moving nanoparticle inside the CNT. Therefore, a better understanding of the mechanism in such loading system may provided some helpful information for the design and optimal of CNT structures. Dynamic behavior of CNTs under moving nanoscale masses or nanoparticles have been concerned by some researchers in recent years, which has being highlighted when CNT are exploited for delivering molecules of drugs, gens and antigens.

The mechanical behavior of CNTs has been explored in two main categories. The first is molecular dynamics simulation, which is limited to systems with a small number of molecules and atoms. The second category is elastic continuum mechanics, which includes classical beam and shell theories for CNTs with large-scale systems. Molecular dynamics simulation is very time consuming and requires huge computational effects. In order to derive the vibration characteristics of nanotube structures, the continuum approach is suitable employed to overcome the limitations of the molecular dynamics simulation [1–5].

Dynamic behavior of CNTs under moving loads or nanoparticle have been of concern to some researchers during the recent years. By considering kinematic and dynamic motions of CNTs due to the inside nanoparticles, Natsuki [6], Ghavanloo [7], Kiani [8–10] investigated the vibration of nanotube and nanoplate structures under a moving nanoparticle by using

* Corresponding author.
E-mail address: deng_qingtian@yahoo.com.cn (D. Qing-tian).

0307-904X/$ - see front matter © 2013 Elsevier Inc. All rights reserved.
http://dx.doi.org/10.1016/j.apm.2013.02.020

nonlocal Rayleigh, Timoshenko and higher-order beam theories, through which they studied effects of small-scale parameter, velocity of the nanoparticle on the dynamic deflection of the nanotube structures. Kiani [11] presented an analytical method for the forced vibration of an elastically connected double-carbon nanotube system carrying a moving nanoparticle based on the nonlocal elasticity theory, and effects of different parameters on the dynamic responses are discussed.

This paper described the vibration characteristics of a SWCNT embedded in an elastic medium under a moving nanoparticle with different constrained conditions. The nanotube is modeled by using Euler–Bernoulli beam theory. By introducing the critical velocities of the moving nanoparticle and considering three different boundary conditions, the dynamic deflection of SWCNTs are then examined through various numerical calculations. And the effects of the velocity and excitation frequency parameters are then studied in some detail.

2. Theoretical analysis

Fig. 1 shows the model of a single-walled carbon nanotube embedded in an elastic medium, where x is the axial coordinate of the nanotube and x_P is the coordinate of the moving load. The nanotube has a length L, effective thickness of the tube h, diameter d and subjected to a moving load $P(t)$, which moves along the axial direction of the nanotube with a constant velocity v_P. The elastic medium is modeled by using the Winkler spring model, which has been widely used to analyze the mechanical properties of embedded CNTs.

By neglecting the rotary inertia and based on the classic Euler–Bernoulli beam model, the equation of motion of the transverse vibration in CNTs is given by

$$\rho A\frac{\partial^2 w}{\partial t^2}+EI\frac{\partial^4 w}{\partial x^4}=p, \tag{1}$$

where $w(x,t)$ is the deflection of CNTs. ρ is the mass density. E, I and A are the elastic modulus, the moment of inertia and the area of the cross-section. p is the distributed transverse force acted on the CNTs. By considering the effects of both elastic medium and internal nanoparticle acting on the CNTs, the Eq. (1) can be rewritten as

$$\rho A\frac{\partial^2 w}{\partial t^2}+EI\frac{\partial^4 w}{\partial x^4}=p_1+p_2, \tag{2}$$

where p_1 is the interaction pressure per unit axial length acting on the outermost layer due to the surrounding elastic medium can be given by Winkler-like model

$$p_1=-kw, \tag{3}$$

where the negative sign indicates that p_1 is opposite to the deflection of the outermost tube and k is a constant determined by the material constants of the elastic medium, the outermost diameter of the SWCNT, and the wave-length of the vibrational modes.

p_2 is the moving transverse load acted on the internal surface of tube, and it can be written as

$$p_2(x,t)=P(t)\delta(x-x_P), \tag{4}$$

$$P(t)=P_0\sin\Omega t, \tag{5}$$

where δ is the Dirac-delta function, P_0 is the amplitude of the moving load, Ω is the excitation frequency of the moving load, x_P is the coordinate of the moving load and $x_P = v_P t$.

Assume that the SWCNT have the same end conditions, so the tube share same vibrational mode $Y(x)$ determined by

$$\frac{d^4Y(x)}{dx^4}=\lambda^4Y(x), \tag{6}$$

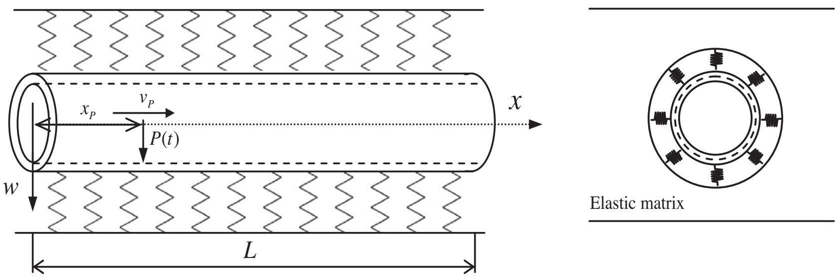

Fig. 1. A SWCNT embedded in an elastic medium under a moving load.