Commun Nonlinear Sci Numer Simulat 65 (2018) 272–298

Contents lists available at ScienceDirect

Commun Nonlinear Sci Numer Simulat

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

Research paper

Nonlinear behaviour and mass detection sensitivity of geometrically imperfect cantilevered carbon nanotube resonators

Hamed Farokhi*, Michael P. Païdoussis, Arun K. Misra

Department of Mechanical Engineering, McGill University, Montreal, Québec H3A 0C3, Canada

A R T I C L E I N F O

Article history:
Received 16 May 2017
Revised 25 April 2018
Accepted 16 May 2018
Available online 17 May 2018

Keywords:
Nanoresonator
Geometric imperfection
Mass detection
Modified couple stress theory
Kelvin–Voigt damping

A B S T R A C T

This study analyzes numerically the nonlinear static and dynamic behaviours as well as the mass detection sensitivity of a geometrically imperfect cantilevered carbon nanotube (CNT) resonator. More specifically, a new nonlinear model is developed for the cantilevered CNT nanoresonator, taking into account the effects of the initial curvature and cross-sectional area imperfection; furthermore, the new nonlinear model accounts for nonlinear damping and small-scale effects, employing the Kelvin–Voigt damping model and the modified couple stress-based elasticity theory, respectively. The electrostatic interactions in the CNT nanoresonator are modelled through use of a new electrostatic load model, previously developed by the authors. The nonlinear equation of motion of the geometrically imperfect cantilevered CNT nanoresonator is obtained making use of Hamilton's principle as well as the inextensibility condition. The electromechanical continuous model of the nanoresonator is reduced into a high-dimensional discretized model employing the Galerkin method. The discretized model, consisting of a set of coupled nonlinear ordinary differential equations, is solved numerically employing a continuation technique. The nonlinear behaviour of the nanoresonator is studied and the effect of different parameters on the static deflection and dynamic response is examined. Furthermore, the mass detection sensitivity of the nanoresonator is examined in detail and methods are proposed for enhancing the detection sensitivity.

© 2018 Elsevier B.V. All rights reserved.

1. Introduction

Nanoelectromechanical systems (NEMS) are nano-scale devices consisting of integrated mechanical and electrical components designed to work in different environments for various purposes. A special class of NEMS devices are nano resonators [1–4] which have desirable features such as high operating frequency and high quality factor [5–7], and low power consumption. Furthermore, they have very small masses, for instance compared to micro resonators [8,9], and hence are capable of detecting the presence of even a very small particle, since the addition of the particle mass causes a detectable shift in their resonance frequency. Hence, nano resonators are commonly used as resonant sensors [10] for ultra-sensitive detection of mass [11–13], force [14], position [15], and thermal fluctuations [16,17]. Carbon nanotubes (CNTs) possess the desired mechanical and electrical properties to be implemented as nanoscale resonators [18].

* Corresponding author.
E-mail address: hamed.farokhi@mail.mcgill.ca (H. Farokhi).

https://doi.org/10.1016/j.cnsns.2018.05.013
1007-5704/© 2018 Elsevier B.V. All rights reserved.

Nomenclature

A	Cross-sectional area of the carbon nanotube (CNT)
E	Young's modulus of the CNT
h	Thickness of the CNT wall
I_0	I for a perfectly circular cross-section
l	Material characteristic length-scale parameter
L	Length of the CNT
m_p	Mass of the particle on the CNT
R_i	Inner radius of the CNT
t	Time
u	Displacement in the axial direction
V_{DC}	DC voltage
V_0	Reference voltage
w_0	Initial curvature in the negative transverse direction
x_p	Location of the particle on the CNT
α	b/L
γ	$m_p/(\rho AL)$
$\boldsymbol{\varepsilon}$	Strain tensor
η	Kelvin–Voigt material viscosity coefficient
$\boldsymbol{\theta}$	Rotation vector
μ	Shear modulus of the CNT
Π	Strain energy
$\boldsymbol{\sigma}$	Stress tensor
$\boldsymbol{\chi}$	Symmetric curvature tensor
ω	Excitation frequency
b	Gap width of the CNT resonator
F_e	Electrostatic load
I	Second moment of area of the CNT
I_f	I/I_0
l_s	$\mu Al^2/(EI_0)$
$\mathbf{m}$	Deviatoric part of the symmetric couple stress tensor
R	Outer radius of the CNT
S	R/b
T	Kinetic energy
$\mathbf{u}$	Displacement vector
V_{AC}	AC voltage
w	Displacement in the transverse direction
x	Axial direction
z	Transverse direction
β	AL^2/I
ϵ	Permittivity of the gap medium
ε_0	Axial strain of the centreline of the CNT
η_s	η/τ
κ	Curvature of the centreline of the CNT
ξ	$\pi\epsilon L^4V_0^2/(EI_0b^2)$
ρ	Mass density of the CNT
τ	$\sqrt{\rho AL^4/(EI_0)}$
ψ	Rotation angle of the centreline with respect to the x axis
Ω	$\omega\tau$

1.1. Literature review

Widespread applications of nano resonators and the challenges in their modelling have drawn the attention of many researchers around the world and have motivated a great deal of research. Many theoretical and experimental investigations have been carried out on the characteristics of nano resonators. The theoretical studies in the literature are usually based on continuum models; however, some studies have also been carried out utilizing molecular models. In what follows, a concise review of the literature is presented, by surveying the studies based on continuum models as well as experimental investigations.

Download English Version:

https://daneshyari.com/en/article/7154475

Download Persian Version:

https://daneshyari.com/article/7154475

Daneshyari.com