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Application of Modified Couple Stress Theory and Homotopy Perturbation Method in Investigation of Electromechanical Behaviors of Carbon Nanotubes

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Abstract. The paper presents the size-dependant behaviors of the carbon nanotubes under electrostatic actuation using the modified couple stress theory and homotopy perturbation method. Due to the less accuracy of the classical elasticity theorems, the modified couple stress theory is applied in order to capture the size-dependant properties of the carbon nanotubes. Both of the static and dynamic behaviors under static DC and step DC voltages are discussed. The effects of various dimensions and boundary conditions on the deflection and pull-in voltages of the carbon nanotubes are to be investigated in detail via application of the homotopy perturbation method to solve the nonlinear governing equations semi-analytically.

AMS subject classifications: 35Q70

Key words: Carbon nanotubes, modified couple stress theory, homotopy perturbation method, electrostatic actuation.

1 Introduction

Carbon nanotubes (CNTs) have found extensive potential and actual applications in high-level technologies ranging from medicine to engineering, since its discovery by Iijima in 1991 [1–5]. Due to the wide applications can be supposed for the CNTs in various conditions, many scientists have studied their different mechanical behaviors such as buckling loads or vibration properties. For example, Koochi et al. presented a new approach to model the buckling and stable length of multi-walled CNT probes near graphite sheets [6]. They applied a hybrid nano-scale continuum model based on Lennard-Jones potential to simulate the intermolecular force-induced deflection of the

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multi-walled CNTs and determined their stable lengths as a function of geometrical and material characteristics, initial gap and number of graphene layers.

In another research, Fakhrabadi et al. studied the vibrational behaviors of the CNTs using molecular mechanics and artificial neural network [7]. They applied molecular mechanics-based finite element method in order to compute the natural frequencies of the CNTs with various lengths and diameters and used the artificial neural network to predict the frequencies of the unmodeled CNTs. There can be found many other papers relating to the nano mechanical behaviors of the CNTs showing their capabilities to be utilized in various utilizations [8–10].

One of the main applications of the CNTs is in nano electromechanical systems (NEMS). NEMS are the miniaturized forms of the micro electromechanical systems (MEMS) composing of nano structures such as nano beams, shells, plates, tubes or other similar structures sensed or actuated electrically. Electrothermal, piezoelectric and electrostatic are more common actuation mechanisms in MEMS and NEMS [11–13]. But, the electrostatic actuation technique is more applicable than the others specially for actuation of the CNTs. Electrothermal actuators can produce high output force by low voltages, but the temperature generated by thermal actuator would be extremely high which can reach more than 800°C. The advantages of this actuator are that it can be fabricated easily; it can generate large force and deflection by low voltage and needs smaller chip area. But, the disadvantage is that the generated temperature is so high that it requires passive or active cooling system to reduce the temperature for certain applications of high bandwidth. The requirement to the effective powerful cooling systems in this actuation mechanism limits its application drastically, especially for the NEMS. Thus, for the system considered in this paper, it cannot be applied. On the other hand, piezoelectric actuation technique produces large forces and high power density, but the displacements generated are so small. In addition, there are some limitations in the piezoelectric actuators such as creep and hysteresis reducing the accuracy and high-frequency response capability of the actuators. The mentioned drawbacks do not allow us to apply it for the current case. Finally, in electrostatic actuation, the motion of electrodes is due to electrostatic repulsion by image charges mirrored in the ground plane beneath the suspended structure. This kind of actuator has small actuation energy and high frequency response, but it also has drawbacks such as high driving voltage and low output force. The advantages of this actuation approach make it an appropriate technique for the system studied in this paper and its shortages does not limit it. Because, for the current case, the nano system does not require larger forces and the actuation voltage can be appropriately provided.

NEMS in general and CNT-based NEMS in particular can possess applications in electronic circuits as nano switches, nano capacitors, nano resonators, nano transistors and elements of random access memories. All of the mentioned applications for the NEMS require high-precision conditions. Some experiments revealed that the classical elasticity theories may not have enough accuracy in predicting the mechanical behaviors of the micro and nano structures [14, 15]. Since continuum-mechanics has been widely applied in studying the mechanical and electromechanical behaviors of the micro and nano struc-