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DYNAMIC STABILITY ANALYSIS OF EMBEDDED MULTI-WALLED CARBON NANOTUBES IN THERMAL ENVIRONMENT

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ABSTRACT In the present paper, the dynamic stability of multi-walled carbon nanotubes (MW-CNTs) embedded in an elastic medium is investigated including thermal environment effects. To this end, a nonlocal Timoshenko beam model is developed which captures small scale effects. Dynamic governing equations of the carbon nanotubes are formulated based on the Timoshenko beam theory including the effects of axial compressive force. Then a parametric study is conducted to investigate the influences of static load factor, temperature change, nonlocal parameter, slenderness ratio and spring constant of the elastic medium on the dynamic stability characteristics of MWCNTs with simply-supported end supports.

KEY WORDS multi-walled carbon nanotubes, dynamic stability, nonlocal elasticity, thermal environment, small scale effect

I. INTRODUCTION

Carbon nanotubes, since their discovery by Iijima[1], are provided with a wide range of potential application due to their elevated stiffness with extraordinary mechanical and electrical performance. The promising applications of single-walled carbon nanotubes (SWCNTs) in the emerging fields of nanoscience and nanotechnology make great motivation to conduct intense research in different aspects of implementations. In order to fulfill the capacity of carbon nanotubes, it is necessary to comprehend their exceptional mechanical properties. The dynamic stability characteristic is one of the most important topics in the studies of mechanical properties of carbon nanotubes, because in this case the high performance of carbon nanotube can be strongly deteriorated through collapse of the nanostructure.

Investigations of mechanical characteristics of carbon nanotubes have focused both on computational and experimental methods. In the case of experimental studies, several investigations have been performed to approximate Young's modulus of carbon nanotubes[2–5]. However, because of the difficulties in experimental characterization of carbon nanotubes and time consuming atomistic simulations, continuum modeling is perhaps the most computationally efficient method for the behaviors of carbon nanotubes. However, the classical continuum models are unable to take into account the quantum effects arising from the discrete nature of matter at nanoscale.

The theory of nonlocal continuum elasticity was formally initiated by Eringen[6] and Eringen and Edelem[7]. Certain elements of the theory were anticipated in attempts to connect lattice mechanics to

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continuum mechanics. Nonlocal continuum models are intended to extend the continuum approach to smaller length scales while retaining most of its many advantages. The major difference between the classical and nonlocal theories is that the former theory assumes that the stress state at a given point is uniquely determined by the strain state at the same point, whereas in the latter theory, the stress state at a given point is considered a function of the strain state of all points in the body.

The use of nonlocal elasticity for nanostructures was made for the first time by Peddieson et al.[8]. They employed the nonlocal elasticity theory to develop a nonlocal cantilever Euler-Bernoulli beam model used as actuators in small scale systems. Since then, applications of nonlocal continuum mechanics have been demonstrated in different areas. There are so many other works in which the nonlocal continuum elasticity has been used to predict the behavior of carbon nanotubes under different loading conditions[9–22]. The transverse vibration characteristics of hanging non-uniform nanoscale tube including surface stress effect were investigated by Rostai and Haghpanahi[23]. They implemented the Eringen nonlocal elasticity theory to the classical Euler-Bernoulli beam theory to capture the size effect. Soltani et al.[24] examined the nonlinear and quasi-linear vibration behavior of curved carbon nanotubes in an electronic force field using a nonlocal Euler-Bernoulli beam model via an analytical solution approach. Recently, Patel and Joshi[25] investigated the influence of surface deviations in DWCNTs when used as a mass sensing device. Also, Arda and Aydogdu[26] studied the torsional statics and dynamics of embedded carbon nanotubes based on the nonlocal elasticity theory. However, only a limited portion of the literature in concerned with the responses of carbon nanotubes considering the thermal effects. Hsu et al.[27] analyzed the frequency of multi-walled carbon nanotubes (MWCNTs) subjected to thermal vibration using a Timoshenko beam model. An analysis of buckling behavior of SWCNTs under axial compression in thermal environment was performed by Ni et al.[28]. Li and Kardomateas[29] studied the thermal buckling phenomenon of multi-walled carbon nanotubes in an elastic medium using nonlocal elasticity continuum. Zhang et al.[30] developed an elastic multiple column model for column buckling of multi-walled carbon nanotubes subjected to axial compression coupling with temperature change. Recently, Ansari et al.[31] investigated axial buckling characteristics of SWCNTs with various boundary conditions including thermal environment effects. Also, the compressive postbuckling of SWCNTs in thermal environments based on a nonlocal Euler-Bernoulli beam model was studied by Ansari et al.[32].

In the current study, dynamic stability an analysis of embedded MWCNTs subjected to thermal environment is investigated based on the nonlocal elastic Timoshenko beam model. The nonlocal elastic beam model developed has the capability to take the small scale effects into account. A Pasternak-type elastic foundation is employed to represent the interaction of the MWCNT and the surrounding elastic medium. A parametric study is conducted to investigate the influences of static load factor, temperature change, nonlocal elastic parameter, slenderness ratio and spring constant of the elastic medium on the dynamic stability characteristics of the MWCNTs with simply-supported end supports.

II. GOVERNING EQUATIONS FOR AN EMBEDDED MWCNT IN THERMAL ENVIRONMENT

As can be seen from Fig.1, a carbon nanotube of length L, Young's modulus E, shear modulus G, density ρ, Poisson's ratio ν, cross-sectional area A, and cross-sectional moment of inertia I in thermal environment subjected to an axial excitation compressive load $\bar{P}(t)$ and a lateral load $\bar{F}(t)$ is considered. A coordinate system (x, y, z) is introduced on the central axis of the carbon nanotube, whereas the x axis is taken along the axial direction of the carbon nanotube, the y axis in the tangential direction and the z axis is taken along the radial direction. Also, the origin of the coordinate system is selected at the left end of the carbon nanotube. It is assumed that the deformations of the carbon nanotube take place in the x-z plane. Thus, suppose $U(x,t)$ and $W(x,t)$ are displacements corresponding to

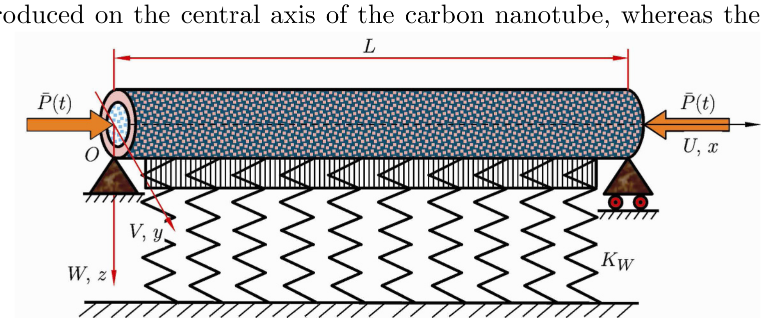

Fig. 1 Schematic of a MWCNT: kinematic parameters, coordinate system, geometry and loading.