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Nanofluidic flow-induced longitudinal and transverse vibrations of inclined stocky single-walled carbon nanotubes

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Abstract

Dynamic interaction of an inclined stocky single-walled carbon nanotube (SWCNT) and a viscous nanofluid flow in the context of nonlocal continuum theory of Eringen is of concern. The SWCNT is modeled based on the nonlocal Timoshenko and higher-order beam theories. To this end, the governing equations of an inclined SWCNT are constructed for each nonlocal beam by taking into account the applied interaction forces on the inner surface of the SWCNT. By employing a slip-flow model and using Newton's second law, the governing equations of the viscous nanofluidic flow inside the SWCNT are obtained. Through combining the resulting governing equations of the SWCNT and those of the nanofluidic flow, the dimensionless governing equations of the SWCNT conveying nanofluid flow are established. Using Galerkin method, the discrete form of the governing equations is obtained for each nonlocal beam model. In the case of a SWCNT with simply supported and immovable ends, the resulting sets of ordinary differential equations are solved in the time domain via an efficient scheme. The effects of the slenderness ratio, small-scale parameter, speed and density of the nanofluid flow, inclination angle, and initial axial force within the SWCNT on the maximum values of dynamic longitudinal and transverse displacements as well as maximum values of nonlocal axial force and bending moment within the SWCNT are examined and discussed.

Keywords: Nanofluidic flow-induced vibration; Single-walled carbon nanotube (SWCNT); Nonlocal Timoshenko beam model; Nonlocal higher-order beam model; Galerkin method

1. Introduction

The use of carbon nanotubes (CNTs) holds a great promise in medical applications. A research by Zhao et al. [1] revealed that CNTs could be used as scaffolding between broken bones to help the body in restoring the break zones. Another possible usage of CNTs would be in detection and treatment of cancer [2]. In an

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Nomenclature

$\bar{u}^T/\bar{w}^T$, and $\bar{u}^H/\bar{w}^H$ dimensionless longitudinal/transverse displacements of the SWCNT modeled based on the nonlocal Timoshenko and higher-order beam theories, respectively
$(N_b^l)^T/(M_b^l)^T$, and $(N_b^l)^H/(M_b^l)^H$ local axial force/bending moment within the SWCNT in which modeled based on the nonlocal Timoshenko and higher-order beam theories, respectively
$(N_b^{nl})^T/(M_b^{nl})^T$, and $(N_b^{nl})^H/(M_b^{nl})^H$ nonlocal axial force/bending moment within the SWCNT in which modeled based on the nonlocal Timoshenko and higher-order beam theories, respectively
$(Q_b^{nl})^T$ and $(Q_b^{nl})^H$ nonlocal resultant shear force within the SWCNT based on the nonlocal Timoshenko and higher-order beam theories, respectively
β^T and β^H ratio of the average speed of the nanofluidic flow to the shear wave velocity of the SWCNT based on the nonlocal Timoshenko and higher-order beam models
g, g_x, and g_z gravitational acceleration, its components along the x and z axes
v_f, c, and x_f velocity profile, average speed, and location of the nanofluidic's front
ρ_f, A_f, and I_f density, cross-sectional area, and moment inertia of the plug-like nanofluidic flow
$\overline{m}_f$ ratio of the mass weight of the nanofluid medium to that of the SWCNT
T_0 initial axial force within the SWCNT
P pressure of the inside nanofluidic flow
A_i cross-sectional area of the nanofluid flow
η_{fe} effective viscosity of the nanofluid flow
τ_{rx} shear stress field of the nanofluidic medium
Λ_f coefficient of the longitudinal interaction force
f_t tangential component of the interaction force on the SWCNT due to the nanofluidic flow
f_n^T and f_n^H normal component of the applied interaction force on the SWCNT due to the nanofluidic flow modeled based on the nonlocal Timoshenko and higher-order beam theories, respectively
Kn Knudsen number
t_b, r_m, and l_b wall's thickness, average radius, and length of the equivalent continuum structure (ECS), respectively
ρ_b, A_b, and I_b density, cross-sectional area, and moment inertia of the ECS, respectively
D_i and D_o inner and outer diameters of the ECS, respectively
E_b and G_b elasticity and shear elasticity modulus of the ECS, respectively
e_0a small-scale parameter
μ dimensionless small-scale parameter
λ slenderness ratio of the ECS
θ^T angle of rotation of the ECS modeled based on the nonlocal Timoshenko beam theory
k_s shear correction factor
ψ^H angle of rotation of the ECS modeled based on the nonlocal higher-order beam theory
H Heaviside step function
MDAF_u, MDAF_w, MDAF_N, and MDAF_M maximum dynamic amplitude factors of the normalized longitudinal and transverse displacements, nonlocal axial force, and nonlocal bending moment of the SWCNT, respectively

attempt to cure cancer, a research by Kam and Dai [3] indicated that CNTs might transport proteins across cell membranes. Staii et al. [4] used CNTs in detection of DNA sequences. Staii et al. [5] built an electronic nose by making CNTs transistors in conjunction with single-stranded DNA molecules. Subsequently, they could discriminate different odors. The use of CNTs as nanopipes also holds interesting potential applications in diverse branches of medical sciences such as drug delivery [6–9] and as alternative nanodevices for vaccine