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The influence of size effect on flapwise vibration of rotating microbeams

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ABSTRACT

This paper deals with flapwise frequency analysis of rotating microbeams connected to a hub by incorporating size effect phenomena. Hamilton principle in conjunction with first shear deformation beam theory and symmetric–deviatoric couple stress theory (the modified version of couple stress theory developed by Yang et al.) is used to derive governing equations and corresponding boundary conditions. The classical first shear deformable beam model and also size-dependent Euler–Bernoulli beam model can be recovered from the present model. To examine free vibration behavior of the rotating microbeam, finite element formulation is developed by applying the corresponding weak form equations. Finally, the influence of size effect on free flapwise vibration behavior of a rotating cantilever microbeam is investigated by considering different parameters i.e., dimensionless material length scale parameter, dimensionless angular velocity, dimensionless radius of hub and slender ratio.

1. Introduction

Experimental investigations proved that the classical continuum mechanics theories are incapable of predicting mechanical behavior of structures in micron scale due to their size-dependency. For instance in the torsion test of thin copper wires in micron scale, Fleck, Muller, Ashby, and Hutchinson (1994) and also Liu et al. (2013) reported that decrease of wires diameter leads to a significant increase of the torsional hardening. Lam, Yang, Chong, Wang, and Tong (2003) during bending tests of epoxy microbeams detected a significant enhancement of bending rigidity when the beam thickness lessens. Son, Jeong, and Kwon (2003) observed a strong size effect during the bending test of Aluminum and gold (Au) microcantilever. Motz, Schöberl, and Pippan (2005) carried out micro-bending tests of thin copper beams and reported a size-dependent behavior for the copper microbeam.

Recently, Yang, Chong, Lam, and Tong (2002) proposed a higher-order elasticity theory which is capable of capturing size effect with only one material length parameter besides two Lamé parameters. This non-classical elasticity theory has been become popular and many researchers have employed this higher-order theory to develop size-dependent structure models and investigate size effect on mechanical behavior of microstructures. Some of these researches can be outlined as: a Bernoulli–Euler beam model for static analysis and comparison study with experimental data by Park and Gao (2006), variational formulation of the modified couple stress theory and its application to a simple shear problem by Park and Gao (2008), nonlinear Bernoulli–Euler beam model for static bending, postbuckling and free vibration analysis Xia, Wang, and

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Yin (2010), a functionally graded Timoshenko beam formulation for static and dynamic analysis by Asghari, Rahaeifard, Kahrobaiyan, and Ahmadian (2011), free vibration analysis for single-layered graphene sheets (SLGS) resting on an elastic matrix as a Pasternak foundation model by Akgöz and Civalek (2012), derivation of nonlinear governing equations of a Mindlin microplates for free vibration analysis by Ke, Wang, Yang, and Kitipornchai (2012a), spectral element analysis of a circular doubly symmetric spinning microbeam embedded in an elastic medium by Mustapha and Zhong (2012), nonlinear free vibration of functionally graded microbeams considering von Kármán geometric nonlinearity by Ke, Wang, Yang, and Kitipornchai (2012b), derivation of nonlinear governing equations and dynamics analysis of geometrically imperfect microbeams and by Farokhi, Ghayesh, and Amabili (2013), free vibration analysis of axially functionally graded tapered Bernoulli–Euler microbeams by Akgöz and Civalek (2013), thermal effect on natural frequencies and critical buckling load of functionally graded microbeams based on Euler–Bernoulli and Timoshenko beam theories by Nateghi and Salamat-talab (2013), a unified higher order beam theory for determination of critical buckling load of a functionally graded microbeam embedded in elastic Pasternak medium by Şimşek and Reddy (2013), functionally graded Kirchhoff and Mindlin plate models for static bending, buckling and free vibration behavior by Thai and Choi (2013), dynamic stability analysis of functionally graded higher-order shear deformable cylindrical microshells by Sahmani, Ansari, Gholami, and Darvizeh (2013), in-plane and out-of-plane motion characteristics of microbeams with modal interactions Ghayesh, Farokhi, and Amabili (2014), modeling of a functionally graded micro-ring segment for the analysis of coupled extensional–flexural waves by Mustapha (2014), buckling analysis of microbeams with high order theories and general boundary conditions by Mohammad-Abadi and Daneshmehr (2014a), a comparison study between constitutive and Euler–Bernoulli beam models and also experimental data by Dehrouyeh-Semnani (2014), micro-inertia effects on the dynamic characteristics of Euler–Bernoulli micro-beams by Fathalilou, Sadeghi, and Rezazadeh (2014), an investigation of buckling analysis of micro composite laminated Euler–Bernoulli and Timoshenko beams by Mohammad Abadi and Daneshmehr (2014b), fluid–Structure interaction in microchannel using Lattice Boltzmann method and finite element method by Esfahanian, Dehdashti, and Dehrouyeh-Semnani (2014a, 2014b), thermo-mechanical buckling behavior of functionally graded microbeams embedded in elastic Winkler medium based on sinusoidal shear deformation beam theory by Akgöz and Civalek (2014), stability analysis of a capacitive functionally graded microbeams by Abbasnejad, Rezazadeh, and Shabani (2013), nonlinear modeling and free vibration analysis of curved microtubes conveying fluid by Tang, Ni, Wang, Luo, and Wang (2014a), axisymmetric postbuckling analysis of functionally graded annular microplates using the physical neutral plane by Ke, Yang, Kitipornchai, and Wang (2014), vibration analysis of a microbeams in flow by Tang, Ni, Wang, Luo, and Wang (2014b), nonlinear vibrations of functionally graded Mindlin microplates based on the modified couple stress theory by Ansari, Faghih Shojaei, Mohammadi, Gholami, and Darabi (2014), developing a conical thin shell model and free vibration analysis of the microshells by Zeighampour and Tadi Beni (2014), a discussion on evaluation of material length scale parameter based on micro-cantilever test by Dehrouyeh-Semnani and Nikkhah-Bahrami (2015a), nonlinear static and free vibration analysis of microbeams based on the nonlinear elastic foundation by Şimşek (2014), thermo-mechanical dynamics of perfect and imperfect Timoshenko microbeams with temperature-dependent mechanical properties by Farokhi and Ghayesh (2015), free vibration analysis of shear deformable functionally graded cylindrical shell by Tadi Beni, Mehralian, and Razavi (2015), dependency of material length scale parameter to higher order elasticity theory unlike Lamé parameters by Dehrouyeh-Semnani (2015), consideration of spatial variation of the length scale parameter in static and dynamic analyses of functionally graded annular and circular micro-plates by Eshraghi, Dag, and Soltani (2015), a discussion on incorporating the Poisson effect in microbeam models using experimental data by Dehrouyeh-Semnani and Nikkhah-Bahrami (2015b), nonlinear bending and postbuckling of functionally graded Mindlin rectangular microplates considering the physical neutral plane position by Ansari, Gholami, Faghih Shojaei, Mohammadi, and Darabi (2015), nonlinear forced oscillation of microplates considering von Kármán nonlinearity by Ghayesh and Farokhi (2015), dynamics and instability of current-carrying microbeams in a longitudinal magnetic field by Wang, Liu, and Dai (2015), developing a damped sandwich microbeam model with viscoelastic core and elastic faces for vibration damping analysis and by Dehrouyeh-Semnani, Dehrouyeh, Torabi-Kafshgari, and Nikkhah-Bahrami (2015), dynamic analysis of composite laminated beams by considering different beam theories by Mohammad-Abadi and Daneshmehr (2015), the influence of size-dependent shear deformation on static deflection, critical buckling and natural frequencies of microstructures-dependent beam using finite element method by Dehrouyeh-Semnani and Nikkhah-Bahrami (2015c), the coupled three-dimensional flexural vibrations of a micro-rotating shaft–disk system, as a basic model for micro-engines by Hashemi and Asghari (2015), developing a functionally graded sandwich microbeam and investigation of static bending, buckling and free vibration behavior of the microbeam by Thai, Vo, Nguyen, and Lee, 2015 and thermal buckling analysis of micro composite laminated beams based on different beam theories by Mohammadabadi, Daneshmehr, and Homayounfard (2015).

It is very important to know the dynamic characteristics of rotating microblades for reliable and economic designs of microsystems such as microturbine (Mehra et al., 2000; Spadaccini et al., 2002; Peirs, Reynaerts, & Verplaetsen, 2004; Carli, Brunelli, Bertozzi, & Benini, 2010; Wang, Wang, Shan, Guo, & Xu, 2013). But, the available literature associated with mechanical behavior of rotating structures on the basis of classical elasticity theories (Rao, 1991; Yoo & Shin, 1998; Chaviaropoulos, 2001; Yoo, Lee, & Shin, 2005; Hosseini & Khadem, 2007; Huang, Lin, & Hsiao, 2010; Allahverdizadeh, Mahjoob, Eshraghi, & Asgharifard-S, 2012; Arvin & Bakhtiari-Nejad, 2013; Li, Zhang, & Zhu, 2014; Tang, Li, Wu, & Lee, 2015) can't be implemented to study behavior of rotating microstructures when the role of size-dependency is great of importance. Therefore, it sounds necessary to investigate vibration characteristics of the rotating microstructures by incorporating size effect.