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Torsional vibration of bi-directional functionally graded nanotubes based on nonlocal elasticity theory

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Abstract

The equation of torsional motion is presented in this paper to investigate the free torsional vibration behaviors of tubes made of a bi-directional functionally graded (FG) material, which is composed of two different materials with continuously varying along the radius and length directions. To incorporate the size effect of long-range forces, the nonlocal elasticity theory is employed to derive the difference equation of torsional motion, which can be reduced to the classical governing equation by simply setting a zero nonlocal parameter. Supposed that the effective material properties of the nanotube vary in the length direction according to an exponential distribute function and in the radius direction according to a power-law function. The closed-form solutions of torsional frequencies and mode shapes are derived. It is shown that the torsional frequencies can be significantly affected by the through-radius and through-length gradings of the bi-directional FG nanotubes and hence can be prescribed by tailoring the bi-directional nano-structures of the FG material. The torsional frequencies can be increased with the decreasing nonlocal parameter, whereas the size-dependent behaviors on the mode shape cannot be observed.

Key words: Bi-directional functionally graded material, Nonlocal elasticity theory, Torsional vibration, Size dependent effect

1. Introduction

Owing to new demands and the developments of the advance production technology, some functionally graded (FG) materials made of two (or more) different materials can be developed [1, 2]. FG materials are gaining high interest for engineering applications because of their excellent performances (e.g., by simultaneously combining ceramic and metal, the FG material may be simultaneously resistant to thermal and mechanical forces). FG material may be referred to as a composite structural system with spatial gradient of macroscopic properties by tailoring its nanostructures [3, 4]. Owing to the superior properties, FG materials are commonly applied for structural components, including tube, beams, and plates, and therefore, their static and dynamic behaviors are studied by may researchers during the last decade [5–9].

From the survey of open literature, it is found that most of the previous works are related to conventional FG material varying its properties along only one-direction. When the temperature or mechanical loading distribution in structural components may exist in two or three directions, which in turn requires a need for a new kind of FG materials whose properties varying along two or three directions. To this end, the vibration and buckling behaviors of macroscopic beams made of bi-directional FG materials have been recently studied by some authors [10–13].

Micro/nano-scaled FG component is gaining high interest because of the developments of the advance micro-/nano-electro-mechanical systems (MEMS/NEMS). For instance, the FG components consisting of shape memory alloy films may have a nano-scaled thickness [14]. Micro/nano-scaled FG structure typically suffers from size effects, in contrast to its larger counterpart in the macroscopic world. Due to size-dependent phenomenon of micro/nano-scaled FG components, the direct use of classical elasticity model may fail in assessing the size-dependent dynamic behaviors, which are predominant factors in designing the ultimate device performance in MEMS/NEMS.

In fact, nano-scaled FG components suffer from considerably higher effects of inter-atomic long-range forces than their macroscopic counterparts. To incorporate the effects of long-range forces, the nonlocal elasticity theory [15] was presented by treating the total stress field at a point as a nonlocal stress field depending on the strain field in the whole body. The size effects of inter-atomic long-range forces can be attributed to lattice dynamic theory and the experimental phenomena on phonon dispersion, and have been taken into account to assess the static and dynamic behaviors of various nano/micro-scaled structures [16–28]. The long-range effects can be significantly observed on the bending, buckling and vibration behaviors of bi-directional FG nanobeams based on the nonlocal elasticity theory [29–31]. The torsional behaviors should be taken into account when the nanotubes subjected to the external torques in some basic components of NEMS, including actuators, oscillators,and small-scaled shafts. There have been few studies related to the size-dependent torsional vibration of nanotubes.

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