ARTICLE IN PRESS

Journal of Sound and Vibration xxx (2017) 1–22

Contents lists available at ScienceDirect

Journal of Sound and Vibration

journal homepage: www.elsevier.com/locate/jsvi

Nonlinear dynamic stability of the orthotropic functionally graded cylindrical shell surrounded by Winkler-Pasternak elastic foundation subjected to a linearly increasing load

Kang Gao, Wei Gao*, Di Wu, Chongmin Song

School of Civil and Environmental Engineering, The University of New South Wales, Sydney, NSW 2052, Australia

ARTICLE INFO

Article history:
Received 19 July 2017
Received in revised form 15 November 2017
Accepted 20 November 2017
Available online xxx

Keywords:
Dynamic stability
FG orthotropic cylindrical shell
Winkler-Pasternak elastic foundation
Linearly increasing load
Inhomogeneous parameters
Damping ratios

ABSTRACT

This paper focuses on the dynamic stability behaviors of the functionally graded (FG) orthotropic circular cylindrical shell surrounded by the two-parameter (Winkler-Pasternak) elastic foundation subjected to a linearly increasing load with the consideration of damping effect. The material properties are assumed to vary gradually in the thickness direction based on an exponential distribution function of the volume fraction of constituent materials. Equations of motion are derived from Hamilton's principle and the nonlinear compatibility equation is considered by the means of modified Donnell shell theory including large deflection. Then the nonlinear dynamic buckling equation is solved by a hybrid analytical-numerical method (combined Galerkin method and fourth-order Runge-Kutta method). The nonlinear dynamic stability of the FG orthotropic cylindrical shell is assessed based on Budiansky-Roth criterion. Additionally, effects of different parameters such as various inhomogeneous parameters, loading speeds, damping ratios and aspect ratios and thickness ratios of the structure on dynamic buckling are discussed in details. Finally, the proposed method is validated with published literature.

1. Introduction

The thin-walled cylindrical shell structure has been widely used in aerospace engineering and other engineering disciplines for many decades, such as propellant tank of space shuttle, the skin of ballistic missile, air receiver tanks, distillation columns and heat exchangers/condensers, due to its outstanding stiffness, large space cover, lower cost and high strength-weight ratio. According to design standards and codes, thin-walled and slender engineering structures not only need to satisfy the load-carrying capacity but also to sustain the stability condition. Therefore, the buckling behaviors of such structures under different effects (axially-loaded [1], pressure-loaded [2], torsional-loaded [3], thermal effect [4], combined axial-radial mechanical load [5], combined thermo-mechanical effect [6] and so on) has been extensively and systematically investigated based on experimental analysis and theoretical method more than half a century. In engineering practice, however, dynamic loads (i.e., wind effect, earthquakes, and stochastic dynamic loads) are commonly and intrinsically applied on the structures, excessively simplifications on such type of loading conditions in both structural analysis and design could compromise the structural safety.

* Corresponding author.
E-mail addresses: kang.gao@unsw.edu.au (K. Gao), w.gao@unsw.edu.au (W. Gao), di.wu@unsw.edu.au (D. Wu), c.song@unsw.edu.au (C. Song).

https://doi.org/10.1016/j.jsv.2017.11.038
0022-460X/

Under such circumstances, a large number of topics on dynamic stability of cylindrical shell keep attracting researchers' attentions. Shaw et al. [7] studied the dynamic instability of the composite cylindrical shells subjected to axial and/or torsional impulse load. Liao and Cheng [8] investigated dynamic buckling characteristics of a laminated composite stiffened or non-stiffened shells subjected to periodic in-plane forces. Based on the energy criterion, Gu et al. [9] presented the plastic buckling of cylindrical shells under external impulsive velocity and asymmetric external loadings, respectively. Despite the fact that fiber-reinforced or laminate composite materials have distinguished stiffness and large strength-weight ratio, severe stress concentrations or singularities at the corners of structure boundaries or interfaces between layers made of different materials would undermine the structure strength and even lead to non-deterministic buckling. Fortunately, an amazingly creative invention named functionally graded materials (FGMs) was proposed by material scientists during the spacecraft project, as a means of ultrahigh temperature resisting materials, which can effectively avoid stress concentrations or singularities due to the smooth transition of the material interface between metal and ceramic. Since then, the studies about FGMs have been completely blooming in almost all associated fields [10–15]. With respect to dynamic buckling of the FG cylindrical shell structures, Ng et al. [16] and Darabi et al. [17] derived the dynamic buckling equations of FG cylindrical shells subjected to periodic axial loading based on small deflection theory and large deflection theory, respectively. While the non-periodic impulsive loading scheme of dynamic buckling for FG cylindrical shell was studied by Sofiyev [18]. Then, after that, in 2004, he also investigated the buckling behavior of an FG cylindrical shell subjected to linearly increasing torsional loading. Huang and Han [19] then analyzed dynamic stability of FG cylindrical shell subjected to the linearly increasing load with the consideration of large deflection and thermal effects. Shariyat [20] studied the dynamic buckling of preloaded, imperfect FGM cylindrical shell subjected to combined axial load and external pressure under thermal environment. Then, he [21] also analyzed dynamic buckling of the abruptly loaded hybrid FG cylindrical shell subjected to thermo-electro-mechanical loads including the temperature-dependent property. Static and dynamic buckling of an imperfect stiffened FG cylindrical shell under axial load was presented by Bich et al. [22]. Based on the *kp*-Ritz method, Lei et al. [23] investigated the dynamic buckling of carbon nanotube-reinforced functionally graded cylindrical panels under periodic loadings.

The dynamic buckling analysis of FG cylindrical shells' studies discussed above was done by considering in homogenous, isotropic graded materials. However, in engineering practices, the material-oriented or orthotropic materials are commonly used in all kinds of fields in order to maximize the material property and optimize the structures, which is even more important for the FG structures. Additionally, due to the nature of fabrication techniques and physical composition, the FGMs are easier to loss of isotropy and become anisotropic with principal directions parallel or/and perpendicular to each layer [24,25]. For example, Kaysser and Ilschner [26] found that a graded Cu-Ni-Sn specimen exhibited a lamellar or duplex structure after the plasma spray processing. A similar phenomenon also reported by Sampath et al. [27] that an equiaxed grain microstructures are observed by Transmission electron micrographs (TEMs). Thus, it is not unnatural to consider the orthotropic FGMs when studying the dynamic buckling behaviors of cylindrical shells.

Nevertheless, investigations involving the orthotropic FGMs cylindrical shells for the dynamic buckling analysis are limited in number. Some works about orthotropic FG cylindrical shells is focused on static buckling, free vibration, force vibration, nonlinear vibration and thermal responses. Sofiyev, as one of the main researchers on orthotropic FG cylindrical shells, has thoroughly investigated such structures under various conditions. For instance, Sofiyev and Kuruoglu [28] presented buckling and vibration characteristics of FG anisotropic cylindrical shell subjected to external pressure was studied by considering shear deformation and rotary inertia. Then, Najafov, Sofiyev and Kuruoglu [29] also investigated the torsional stability and vibration of FG orthotropic cylindrical shell on elastic foundation. The buckling of FG orthotropic cylindrical shells with the consideration of shear deformable subjected to lateral pressure also discussed by Sofiyev et al. [30]. Recently, both the nonlinear free vibration including shear deformable theory and large amplitude vibration on nonlinear Winkler elastic foundation of FG orthotropic cylindrical shells were reported by Sofiyev [31,32]. While other scholars mainly focused on crack analysis and failure behaviors of orthotropic FGMs [33–38]. Rao and Rahman [33] studied the cracks behaviors of orthotropic cylindrical shells by finite element method (FEM). Xu et al. [34] presented the semi-infinite cracks of FG orthotropic materials. By using an equivalent domain integral approach, Dag [38] analyzed the thermal stresses in FG orthotropic cylindrical shells. Then, Dag et al. [36] also discussed the mechanical and thermal effects on fracture failure of orthotropic cylindrical shells.

Despite mentioned studies, up to date, dynamic buckling of FG orthotropic cylindrical shells is a novel topic that cannot be found in the literature. Furthermore, with the application of FG orthotropic cylindrical shells, these structures rest on or embed in elastic foundation/medium have attracted much attention. Damping property (i.e., a non-conservative energy contribution), as one of the most important aspects of engineering dynamics, is also considered in this paper. Therefore, to the best of authors' knowledge, the dynamic stability of an FG orthotropic circular cylindrical shell surrounded by a two-parameter (Winkler-Pasternak) elastic foundation subjected to linearly increasing load with the consideration of damping effect is first investigated here. Equations of motion are derived from Hamilton's principle and the nonlinear compatibility equation is considered by the means of modified Donnell shell theory including large deflection. Then the nonlinear dynamic buckling equation is solved by a hybrid analytical-numerical method (combined Galerkin method and fourth-order Runge-Kutta method). Effects of different parameters such as various inhomogeneous parameters, loading speeds, damping ratios and aspect ratios and thickness ratios of the structure on dynamic buckling are discussed in details. Finally, the proposed method was validated with some results known from literature.

Please cite this article in press as: K. Gao et al., Nonlinear dynamic stability of the orthotropic functionally graded cylindrical shell surrounded by Winkler-Pasternak elastic foundation subjected to a linearly increasing load, Journal of Sound and Vibration (2017), https://doi.org/10.1016/j.jsv.2017.11.038