Composite Structures 108 (2014) 894–904

Contents lists available at ScienceDirect

Composite Structures

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

Three-dimensional free vibration of laminated cylindrical panels with functionally graded layers

P. Malekzadeh [a,*], M. Ghaedsharaf [b]

[a] Department of Mechanical Engineering, Persian Gulf University, Bushehr 7516913798, Iran
[b] Department of Mechanical Engineering, Islamic Azad University, Branch of Shiraz, Shiraz, Iran

ARTICLE INFO

Article history:
Available online 25 October 2013

Keywords:
Free vibration
Laminated cylindrical panels
Functionally graded layers
Finite length
Three-dimensional elasticity
Differential quadrature

ABSTRACT

The three-dimensional (3D) free vibration of laminated cylindrical panels with finite length and functionally graded (FG) layers is presented. The cylindrical panels with two opposite axial edges simply supported and arbitrary boundary conditions at the curved edges can be analyzed via the present approach. The material properties vary continuously through the layers thickness. In order to accurately model the variation of the displacement components through the panel thickness, a layerwise-differential quadrature method (LW-DQM) is employed in this direction. Also, the in-plane variations of the displacement components are approximated using the trigonometric series in the circumferential direction and the DQM in the axial direction. The fast rate of convergence and accuracy of the method are demonstrated through different examples. As applications of the present approach, the free vibration of two common types of sandwich cylindrical panels, i.e. sandwich panels with FG face sheets and ceramic core and sandwich panels with FG core and ceramic/metal face sheets, and also bi-layered FG cylindrical panels are studied. The effects of geometrical and material parameters together with the boundary conditions on the frequency parameters of these types of panels are investigated.

© 2013 Elsevier Ltd. All rights reserved.

1. Introduction

Functionally graded materials (FGMs) refer to heterogeneous composite materials with spatial compositional variation of their constituents which results in continuously varying material properties [1]. The concept of FGMs has been proposed to achieve materials with enhanced thermo-mechanical properties which overcome the drawbacks of the conventional laminated composite materials such as delamination and matrix cracking and also can operate in the extremely harsh thermal environmental conditions while maintaining their structural integrity [1].

Functionally graded cylindrical panels, as important structural components, have widely been used in different branches of engineering such as mechanical, energy and aerospace engineering. However, in comparison with the isotropic and conventional laminated cylindrical panels, the literature on the free vibration analysis of FG cylindrical panels is relatively scarce. In addition, in the most of the existing researches in this regards, single layer FG cylindrical panels have been analyzed. In the following, some of these research works are briefly reviewed.

Pradyumna and Bandyopadhyay [2] carried out the free vibration analysis of FG curved panels using a higher-order shear deformation theory (HSDT). They used the finite element method (FEM) to perform the analysis. Matsunaga [3] investigated the free vibration and stability of FG shallow shells with all edges simply supported according to a HSDT. Tornabene and Viola [4] studied the dynamic behavior of FG parabolic and circular panels and shells of revolution based on the first-order shear deformation theory (FSDT) using the generalized differential quadrature method (GDQM). In another work [5], they investigated the free vibration behavior of moderately thick FG parabolic panels and shells of revolution based on FSDT by proposing a generalization of the power-law distribution. Two different four-parameter power-law distributions were considered for the ceramic volume fraction to generate some symmetric and asymmetric material profiles through the functionally graded shell thickness. The governing equations of motion were discretized using the GDQM. Zahedinejad et al. [6] presented the free vibration analysis of FG curved thick panels under various boundary conditions based on the three-dimensional elasticity theory using the differential quadrature method (DQM). Farid et al. [7] employed the DQM to analyze the three-dimenaional free vibration of thick simply supported FG curved panel resting on two-parameter elastic foundation subjected in thermal environment. Tornabene et al. [8] applied the GDQM to study the vibration behavior of the FG and laminated

* Corresponding author. Tel.: +98 771 4222150; fax: +98 771 4540376.
E-mail addresses: malekzadeh@pgu.ac.ir, p_malekz@yahoo.com (P. Malekzadeh).

0263-8223/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.compstruct.2013.10.024

doubly curved panels and shells of revolution with a free-form meridian based on the FSDT. They performed comparison studies between the results of the Reissner–Mindlin and the Toorani–Lakis theories. Kiani et al. [9] examined the thermoelastic free vibration and dynamic behavior of FG doubly curved panels based on the FSDT subjected to the modified Sanders assumptions. In another work, Kiani et al. [10] performed the staic and dyanmic analysis of FG doubly curved panels resting on the Pasternak-type elastic foundation. Hosseini-Hashemi et al. [11] investigated free vibration of Levy-type thick FG circular cylindrical panels to identify the validity range of two common shell theories, namely, Donnell and Sanders theories. Bich et al. [12] investigated the free vibration characteristics and nonlinear responses of eccentrically stiffened functionally graded cylindrical panels with geometrically imperfections. They derivied the formulation based on the classical shell theory with the geometrical nonlinearity in von Karman–Donnell sense and the smeared stiffeners technique. Neves et al. [13] employed the radial basis functions collocation method to study the free vibration behvior of FG panels according to a HSDT that accounts for through-the-thickness deformation and Carrera's unified formulation. More recently, Malekzadeh et al. [14] extracted the three-dimensional free vibration characteristics of FG cylindrical panels with a cut-out under thermal environment using Chebyshev–Ritz method.

In all of these works [2–14], vibration analysis of single layered FG curved panels and shells were considered. On the other hand, there are several research works on the vibration analysis of laminated and sandwich FG plates and shells, which indicates the importance of these types of FG structural elements; see for example Refs. [15–25]. Hence, in this work, the free vibration analysis of multi-layered cylindrical panels with FG layers and finite length is presented based on the three-dimensional elasticity theory. Due to the intrinsic complexity of the problem formulation based on the three-dimensional elasticity theory, a layerwise-differential quadrature method as an efficient and accurate numerical tool [24–28] is employed to discertize the governing differential equations subjected to the related boundary conditions in the graded direction (thickness direction). Using the DQM enables one to accurately and efficiently discretize the governing differential equations along the graded direction and also implement the related boundary and compatibility conditions. Also, the in-plane variations of the displacement components are approximated by using trigonometric series and the DQM. After validating the present approach through different examples, as important applications, the free vibration of two common types of sandwich cylindrical panels, i.e., sandwich panels with FG face sheets and homogeneous (ceramic) core (type I) and sandwich panels with FG core and homogeneous (ceramic and metal) face sheets (type II), and also bi-layered FG cylindrical panels (type III) are studied. The influences of geometrical and material parameters on the vibration characteristics of these types of panels subjected to different boundary conditions are investigated.

2. Mathematical modeling

Consider a laminated cylindrical panel composed of N_L perfectly bonded FG layers as shown in Fig. 1. A cylindrical coordinate system with the coordinate variables r along the radial direction, θ along the circumferential direction and x along the axial direction are adopted to label an arbitrary material point of the panel. The panel has the total thickness h, mean radius R_m radius of innermost surface R_i, radius of outermost surface R_o, cylindrical panel axial length L_x, total panel angle θ_0 and arc length $L_y(=R_m\theta_0)$. The displacement components of an arbitrary material point (x, θ, r) of the eth layer are denoted as u^e, ϑ^e and w^e in the x, θ and r-directions, respectively. Hereafter, a superscript 'e' is used to denote the properties and field variables of the eth layer.

2.1. FG material properties

It is assume that the FG layers of the panel is made of a mixture of ceramics and metals and the material composition continuously vary such that the innermost surface $(r = R_i^e)$ of the eth layer is ceramic (metal) rich, whereas its outermost surface $(r = R_o^e)$ is metal (ceramic) rich. The effective material properties of the layers are obtained using the rule of mixture. According to this scheme, a typical effective material property P^e of the eth layer can be expressed as,

$$P^e(r) = P_\alpha^e + \left(P_\beta^e - P_\alpha^e\right)\left(V_f^e\right)^p, \quad \text{for } \alpha, \beta = m, c \text{ and } e = 1, 2, \ldots, N_L \tag{1}$$

where $V_f^e\left(= \frac{r - R_i^e}{R_o^e - R_i^e}\right)$ is the volume fraction; $p(\geqslant 0)$ denotes the volume fraction exponent, which is a positive real number; the subscripts m and c refer to the metal and ceramic constituents, respectively.

2.2. Three-dimensional layerwise-differential quadrature formulation

Since the material properties of the panels vary in the thickness direction, it is difficult to analytically solve their 3D free vibration governing equations. Hence, a lyerwise-differntial quadrature approach is adopted in this work. Based on this algorithm, firstly, the cylindrical panel is divided into a set of $N_m(\geqslant N_L)$ mathematical layers in the thickness direction. As the second step, the 3D equations of motion together with the related boundary of each layer and also the compatibility conditions at the interface of two adjacent layers can be achieved by using Hamilton's principle,

$$\int_{t_1}^{t_2} \sum_{e=1}^{N_m} (\delta T^e - \delta \Pi^e) dt = 0 \tag{2}$$

where δT^e and $\delta \Pi^e$ are the variation of the kinetic and potential energies of the eth FG layer, respectively; t is time and t_1 and t_2

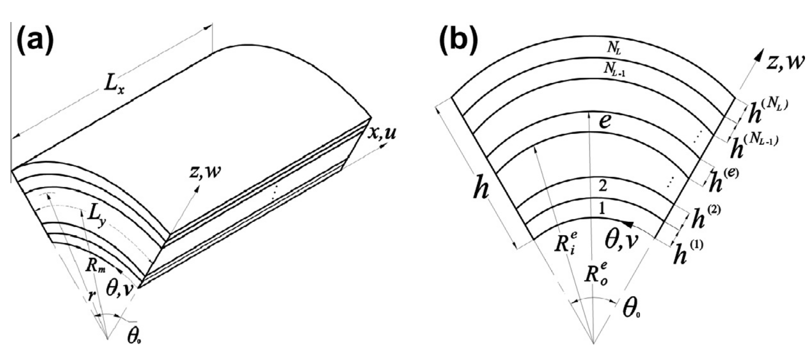

Fig. 1. (a and b): Geometry and coordinate system of the laminated FG cylindrical panels ($h^{(e)}$ is the thickness of the eth layer).

Download English Version:

https://daneshyari.com/en/article/251888

Download Persian Version:

https://daneshyari.com/article/251888

Daneshyari.com