Composite Structures 126 (2015) 16–33

Contents lists available at ScienceDirect

Composite Structures

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

Nonlinear dynamic analysis and vibration of shear deformable eccentrically stiffened S-FGM cylindrical panels with metal–ceramic–metal layers resting on elastic foundations

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ARTICLE INFO

Article history:
Available online 23 February 2015

Keywords:
Nonlinear dynamic analysis
Vibration
Eccentrically stiffened S-FGM cylindrical panels with metal–ceramic–metal layers
First-order shear deformation theory
Elastic foundations

ABSTRACT

Based on first-order shear deformation, this paper investigates the nonlinear dynamic analysis and vibration of shear deformable imperfect eccentrically stiffened functionally graded thick cylindrical panels, taking into account the damping when subjected to mechanical loads. The volume fractions of metal and ceramic are applied by Sigmoid-law distribution for functional graded material (S-FGM) with meta l–ceramic–metal layers. The panels are assumed to be resting on elastic foundations and are reinforced by eccentric longitudinal and transversal stiffeners made of full metal. The nonlinear equations are solved by the Galerkin method and fourth-order Runge–Kutta method. The influences of inhomogeneous parameters, dimensional parameters, stiffeners, elastic foundations, boundary conditions and mechanical loads on the nonlinear dynamic analysis and nonlinear vibration of thick S-FGM cylindrical panels are examined in detail. The results are compared with known results in the literature.

1. Introduction

Functionally graded materials (FGMs) have been widely used for a variety of engineering applications due to their beneficial characteristics such as high stiffness and excellent temperature resistance capacity compared with ordinary materials. The mechanical behaviour of FGM panels, such as bending, vibration, stability, buckling, etc., have attracted the attention of many researchers.

In static analysis of FGM cylindrical panels, many authors focussed on the buckling and post-buckling of panels under mechanic and thermal loading. Shen [1] presented post-buckling analysis for a functionally graded cylindrical panel of finite length subjected to axial compression in thermal environments. Yang et al. [2] studied thermo-mechanical post-buckling analysis of cylindrical panels made of functionally graded materials with temperature-dependent thermo-elastic properties that are graded in the direction of thickness according to a simple power law distribution in terms of the volume fractions of the constituents. Tung [3] investigated the effects of tangential edge constraints on the buckling and post-buckling behaviour of functionally graded flat and cylindrical panels subjected to thermal, mechanical and thermo-mechanical loads and resting on elastic foundations. Duc and Tung [4,5] also introduced an analytical approach to investigate the stability of functionally graded cylindrical panels under axial compression and uniform lateral pressure with temperature effects.

For dynamic analysis of FGM cylindrical panels, Ng et al. [6] focussed on the dynamic stability of simply-supported, isotropic cylindrical panels under combined static and periodic axial forces. Liew et al. [7] dealt with the linear and nonlinear vibration analysis of a three-layer coating-FGM-substrate cylindrical panel with general boundary conditions and subjected to a temperature gradient across the thickness due to steady heat conduction. Yang and Shen [8] obtained free vibration and dynamic instability of functionally graded cylindrical panels subjected to combined static and periodic axial forces and in a thermal environment. Amabili [9] published the results on large-amplitude vibrations of circular cylindrical panels with a rectangular base, simply supported at four edges and subjected to radial harmonic excitation in the spectral neighbourhood of the lowest resonances. Pradhan et al. [10] presented a study of the vibration of a functionally graded cylindrical shell made up of stainless steel and zirconia based on the Rayleigh method. Ovesy and Fazilati [11] conducted dynamic stability analysis of moderately thick cylindrical panels made from FGM by

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http://dx.doi.org/10.1016/j.compstruct.2015.02.056
0263-8223/

employing finite strip formulations based on a Reddy-type third-order shear deformation theory. Farid et al. [12] studied free vibration analysis of an initially stressed thick simply supported functionally graded curved panel resting on a two-parameter elastic foundation (Pasternak model), subjected to a thermal environment using three-dimensional elasticity formulation. Kiani et al. [13] researched active control and dynamic analysis of shallow doubly curved functionally graded material panels integrated with sensor/actuator piezoelectric layers. Alibeigloo and Liew [14] discussed an exact three-dimensional free vibration solution for sandwiched cylindrical panels with a functionally graded core. Recently, Shen and Wang [15] investigated the large amplitude vibration behaviour of a shear deformable FGM cylindrical panel (without stiffeners) resting on elastic foundations in thermal environments.

To provide the benefit of added load-carrying static and dynamic capability, the FGM structures are usually reinforced by stiffeners. Up-to-date stability analysis and vibration of eccentrically stiffened FGM panels have received comparatively little attention. Duc and Quan [16] presented the static nonlinear response of eccentrically stiffened FGM cylindrical panels on elastic foundations subjected to mechanical loads. Based on classical shell theory with geometrical nonlinearity in the von Karman–Donnell sense and the smeared stiffeners technique, Bich et al. [17] considered the governing equations of motion of eccentrically stiffened FGM cylindrical panels with geometric imperfections.

This is the first paper using first-order shear deformation theory to investigate the nonlinear dynamic analysis and vibration of imperfect eccentrically stiffened S-FGM thick cylindrical panels subjected to mechanical and damping loads. The volume fractions of metal and ceramic are applied by the Sigmoid-law distribution (S-FGM) with metal–ceramic–metal layers. The panels are assumed to be resting on an elastic foundation and are reinforced by eccentrically located longitudinal and transversal stiffeners made of full metal. The nonlinear equations are solved by the Galerkin method and fourth-order Runge–Kutta method.

2. Problem formulation

Consider an eccentrically stiffened FGM cylindrical panel of radius of curvature R, length of edges a, b, and uniform thickness h resting on elastic foundations. A coordinate system (x, y, z) is established, in which the (x, y) plane is in the middle surface of the panel and z is in the thickness direction $(-h/2 \leqslant z \leqslant h/2)$, as shown in Fig. 1. The material properties of the FGM panel are varied continuously throughout its thickness direction. It is assumed that the top and bottom surfaces are metal surfaces, and the middle surface is a ceramic one. The panel is reinforced by eccentrically longitudinal and transversal stiffeners (Fig. 2). The width and thickness of the longitudinal and transversal stiffeners are denoted by d_x, h_x and d_y, h_y, respectively; and s_x, s_y are the spacing of the longitudinal and transversal stiffeners. The quantities A_x, A_y are

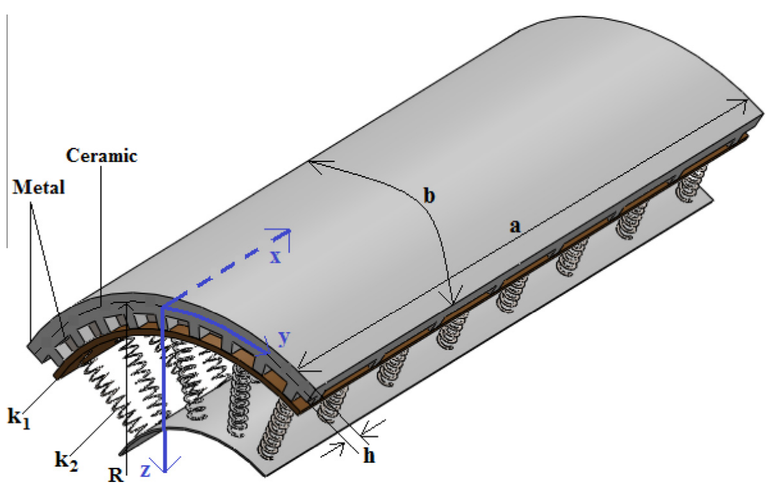

Fig. 1. Geometry and coordinate system of S-FGM eccentrically stiffened cylindrical panels with metal–ceramic–metal layers on elastic foundations.

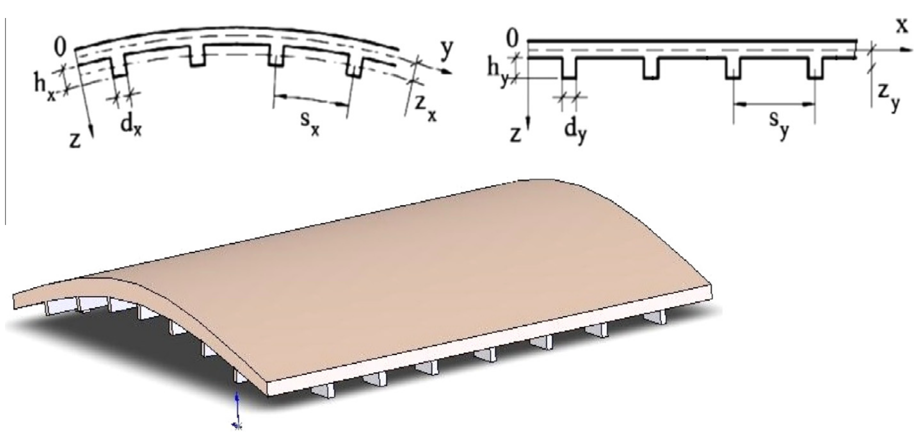

Fig. 2. Geometry of FGM cylindrical panels with x- and y-stiffeners.