Thin-Walled Structures 93 (2015) 10–21

Contents lists available at ScienceDirect

Thin-Walled Structures

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

Dynamic instability of three-layered cylindrical shells containing an FGM interlayer

A.H. Sofiyev [a,*], N. Kuruoglu [b]

[a] Department of Civil Engineering, Faculty of Engineering, Suleyman Demirel University, 32260 Isparta, Turkey
[b] Department of Engineering Mathematics, Faculty of Engineering and Natural Sciences, Bahcesehir University, Istanbul, Turkey

ARTICLE INFO

Article history:
Received 16 December 2014
Received in revised form
27 February 2015
Accepted 3 March 2015
Available online 21 March 2015

Keywords:
FGM interlayer
Three-layered cylindrical shells
Dynamic instability
Unstable region
Time dependent periodic axial load

ABSTRACT

In this study, the dynamic instability of three-layered cylindrical shells containing a functionally graded (FG) interlayer subjected to static and time dependent periodic axial compressive loads are investigated. The governing relations, modified Donnell type dynamic stability and deformation compatibility equations are derived. The governing equations are reduced Mathieu–Hill equation by using Galerkin's method and the expressions for boundaries of unstable regions of three-layered cylindrical shell with an FG interlayer are found. Finally, the effects of variations of volume fractions of FG interlayer and shell characteristics on the magnitudes of boundaries of unstable regions are studied numerically.

1. Introduction

The circular cylindrical shell is one of important element of many engineering areas that can be used in the aircraft fuselages, missiles and space vehicles, structural and non-structural vehicle components, tanks, pipelines etc. The dynamic instability of cylindrical shells under time dependent periodic loads has drawn considerable attention from researchers due to its detrimental and de-stabilizing effects in many engineering applications. The investigation about this phenomenon in elastic systems was first studied by Bolotin [1], who found the dynamic instability regions. Gnuni [2] determined the boundaries of dynamic instability regions of shells, also. Vijayaraghavan and Evan-Iwanowski [3] analytically and experimentally studied parametric instability of circular cylindrical shells subjected to in-plane longitudinal inertia loading arising from sinusoidal base excitation. Kana and Graig [4] studied parametric oscillations of a longitudinally excited cylindrical shell containing liquid.

Following these studies, have emerged series of publications related to the dynamic instability of cylindrical shells under time-dependent periodic loads [5–8]. More recent work on the dynamic instability of homogenous orthotropic cylindrical shells under time-dependent periodic loads has been reported by Bert and Birmann [9] that studied a parametric instability of thick orthotropic cylindrical shells using the high order shell theory. By using a perturbation technique, Argento and Scott [10,11] studied the dynamic instability of layered anisotropic circular cylindrical shells under periodic axial loading. Ng et al. [12] reported the dynamic instability of cross-ply laminated composite cylindrical shells under combined static and periodical axial forces using Love's shell theory. Ganapathi and Balamurugan [13] studied the dynamic instability of laminated composite circular cylindrical sh ells subjected to periodic load, using a C^o shear flexible two-no de axi-symmetric shell element. Park and Kim [14] analyzed the dynamic stability of a completely free isotropic circular cylindrical shell under a follower force. Pellicano and Amabili [15] reported the instability and vibration analysis of empty and fluid-filled circular cylindrical shells under static and periodic axial loads. Pellicano [16] theoretically and experimentally studied dynamic instability of a circular cylindrical shell carrying a top mass under base excitation. Bespalova and Urusova [17] investigated dynamic instability of shells of revolution with alternating curvature under periodic loading.

Functionally graded materials (FGMs) are relatively novel multi-functional materials which were first introduced by Japanese material scientists in 1984 (see, [18]). These materials are made up of mixture of ceramics and metals that are characterized by the smooth and continuous variation in the properties from one surface to the other. Thorough overviews on the FGMs can be found in Refs. [19–21]. Overview of the main events of FGMs and their field of applications published since 2000 have been carried out by Birman and Byrd [22] and Shen [23].

With the increasing use of FG materials in the aerospace engineering, has become more important to examine the dynamic

* Corresponding author. Tel.: +90 246 211 1195; fax: +90 246 237 0859.
E-mail address: abdullahavey@sdu.edu.tr (A.H. Sofiyev).

http://dx.doi.org/10.1016/j.tws.2015.03.006
0263-8231/

instability of FG cylindrical shells. Ng et al. [24] examined dynamic instability analysis of FG cylindrical shell subjected under periodic axial loading. The dynamic instability of simply-supported FG cylindrical shells under an axial harmonic loading have been investigated by Darabi and co-workers, applying Donnell's theory of shells and using Galerkin method and Bolotin's approximation in order to extract the unstable regions [25]. Ansari and Darvizeh [26] presented a general analytical approach to investigate dynamic instability behavior of temperature-dependent FG shells with different boundary conditions. Ovesy and Fazilati [27] investigated the dynamic instability analysis of moderately thick FG cylindrical panels employing finite strip formulations. Lei et al. [28] presented a first-known dynamic instability analysis of carbon nanotube-reinforced functionally graded (CNTR-FG) cylindrical panels under static and periodic axial forces by using the mesh-free kp-Ritz method.

Among the various structural constructions, the sandwich types of structures are commonly used in the aerospace vehicles, because of its outstanding bending rigidity, low specific weight, excellent dynamic characteristics and good fatigue properties. Due to the mismatch in stiffness properties of the coatings-kernel-substrate, sandwich shells are susceptible to delamination, caused by high interfacial stresses, especially under dynamic loadings. The intensity and extent of the stress concentration effects due to the large mismatch in properties can be substantially reduced if the microstructure is gradually changed from that of the metal to that of the ceramic. The most suitable material for these type nuclei is FGMs to minimise such property mismatch effects. For the first time, Pitakthapanaphong and Busso [29] formed the generic three-layer systems containing functionally graded materials (FGM) that studied behavior of these systems.

Modern technology has made it possible to simplify the production and use of sandwich plates and shells containing an FGM interlayer, as well as provide new opportunities for the study of stability and vibration behavior of structural elements, and eventually led to the emergence of new publications in these areas. For instance, Anderson [30] presented a 3-D elasticity solution for a sandwich composite with functionally graded core subjected to transverse loading by a rigid sphere. Venkataraman and Sankar [31] proposed elasticity solution for stresses in a sandwich beam with functionally graded core. Liew et al. [32] presented the vibration of a coating–FGM–substrate cylindrical panel subjected to a temperature gradient. Sofiyev [33] examined the vibration and static stability of composite cylindrical shells containing FG layer subjected to various loads. Li et al. [34] analyzed free vibration of three layered circular cylindrical shells with the FG middle layer. Woodward and Kashtalyan [35] investigated 3D elasticity analysis of sandwich panels with graded core under distributed and concentrated loadings. Wu and Jiang [36] investigated a state space differential reproducing kernel method for the 3D analysis of FGM sandwich circular hollow cylinders with combinations of simply-supported and clamped edges. Sburlati [37] reported an axisymmetric elastic analysis for circular sandwich panels with FG cores. Bui et al. [38] analyzed dynamic behavior of sandwich beams with FG core using a truly mesh free radial point interpolation method. Sobhy [39] investigated the buckling and free vibration of exponentially graded sandwich plates resting on elastic foundations under various boundary conditions. Najafov et al. [40] reported the vibration and stability behaviors of axially compressed truncated conical shells with FG middle layer surrounded by elastic medium. Tornabene et al. [41] presented the stress and strain recovery for functionally graded free-form and doubly-curved sandwich shells using higher-order equivalent single layer theory.

To the authors' knowledge, the study on the dynamic instability of the circular cylindrical shell containing an FG interlayer is not yet available in the literature. In a present study, the solution of this problem is discussed in detail.

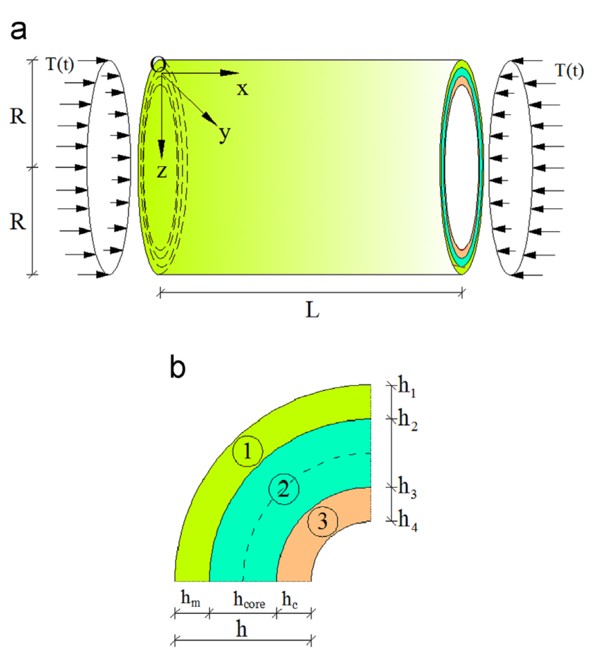

Fig. 1. (a) The coordinate system of three-layered cylindrical shells under time dependent axial compressive load and (b) the sequence of the layers: (1) ceramic, (2) FG interlayer, (3) metal.

2. Formulation of the problem

The FG cylindrical shell that inner and outer surfaces coated with the metal-rich and ceramic-rich, respectively and notes belong to them is presented in Fig. 1. The origin of the coordinate system is selected at the left end in the reference surface of the interlayer of an FG cylindrical shell. x and y axes are directed in the axial and circumferential directions, and the z-axis is perpendicular to two axes, represented in Fig. 1. Thicknesses of the ceramic-rich and metal-rich are h_c and h_m, respectively, the thickness of an FG interlayer is h_{FG} and total thickness of a three-layered shell is $h = h_m + h_c + h_{FG}$. The radius and length of cylindrical shell are R and L, respectively, and $h_1 = -h/2$, h_2, h_3, $h_4 = h/2$ are constants determining the thickness of the layers (Fig. 2).

Three-layered cylindrical shells with an FG interlayer subjected to static and time dependent periodic axial loads that are expressed as follows [24]:

$$T_x^0 = T_0 + T_t \cos(Pt) \tag{1}$$

where T_x^0 is the membrane force for the condition with zero initial moments, T_0 is the uniform static load applied along the edges

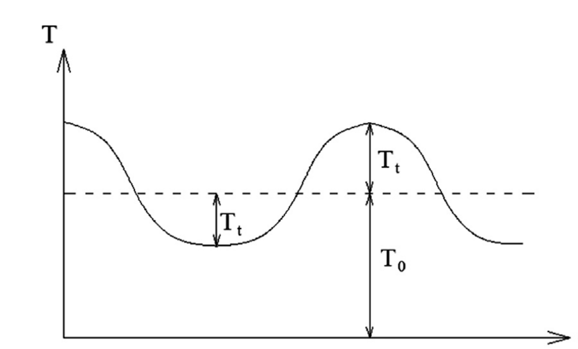

Fig. 2. Variation of the harmonic axial load versus the time.