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Thickness stretching and nonlinear hygro-thermo-mechanical loading effects on bending behavior of FG beams

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Abstract. In this paper, the nonlinear vibration behavior of the spiral stiffened multilayer functionally graded (SSMFG) cylindrical shells exposed to the thermal environment and a uniformly distributed harmonic loading using a semi-analytical method is investigated. The cylindrical shell is surrounded by a nonlinear viscoelastic foundation consisting of a two-parameter Winkler-Pasternak foundation augmented by a Kelvin-Voigt viscoelastic model with a nonlinear cubic stiffness. The distribution of temperature and material constitutive of the stiffeners are continuously changed through the thickness direction. The cylindrical shell has three layers consisting of metal, FGM, and ceramic. The interior layer of the cylindrical shell is rich in metal, while the exterior layer is rich in ceramic, and the FG material is located between two layers. The nonlinear vibration problem utilizing the smeared stiffeners technique, the von Kármán equations, and the Galerkin method has been solved. The multiple scales method is utilized to examine the nonlinear vibration behavior of SSMFG cylindrical shells. The considered resonant case is 1:3:9 internal resonance and subharmonic resonance of order 1/3. The influences of different material and geometrical parameters on the vibration behavior of SSMFG cylindrical shells are examined. The results show that the angles of stiffeners, temperature, and elastic foundation parameters have a strong effect on the vibration behaviors of the SSMFG cylindrical shells.

Keywords: multilayer FG cylindrical shells; internal resonances; spiral stiffeners; thermal environment; nonlinear viscoelastic foundation; subharmonic of order 1/3

1. Introduction

Functionally graded beams are structural elements consisting of two different materials. Due to their low weight and high rigidity, these elements are commonly used in several industries, such as construction, aerospace, transportation, aeronautics, and marine. Therefore, knowing their static characteristic is essential for scientists and engineers. The two constituent materials of conventional composite beams are attached, which increases the risk of delamination. Notably, the continuous evolution of mechanical characteristics from the bottom surface to the top one eliminates the interface between the layers, an area of stress concentration.

Additionally, the FG structures have two essential properties: resistance to mechanical loading through the metal face and thermal loading along the ceramic side. Consequently, these characteristics attract many researchers to study and analyze the mechanical response of these material structures under different solicitations.

During the space plane project in 1984, Japanese researchers developed FG materials to resist ultra-high temperatures. The FG structures have been tested under high-temperature gradients across the cross-sectional thickness. Nowadays, FG materials are alternative materials widely used in aerospace, energy sources, nuclear reactors, optical, biomechanical, civil, automotive, mechanical, chemical, and shipbuilding industries (Sayyad and Ghugal 2019).

FG beams are often subjected to coupled (mechanical, thermal, and moisture) loading in several engineering areas.

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