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Thermal vibration of magnetostrictive functionally graded material shells by considering the varied effects of shear correction coefficient

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ABSTRACT

This paper investigates the thermal vibration of magnetostrictive functionally graded material (FGM) cylindrical shells by using the generalized differential quadrature (GDQ) method based on the first-order shear deformation theory (FSDT). The varied effects of shear correction coefficient are employed and obtained by using the total strain energy principle. The computed and varied values of shear correction coefficient are usually functions of magnetostrictive layer thickness, FGM power law index and environment temperature. In the thermo-elastic stress–strain relations, the simpler form stiffness of FGM shells and the effect of the magnetostrictive coupling terms with velocity feedback control under linear temperature rise are considered. The effects of magnetostrictive layer thickness, control gain values, environment temperature and FGM power law index on the thermal vibration of magnetostrictive FGM thick cylindrical shells are obtained and analyzed.

1. Introduction

The background of this study is to improve the assumed constant value 5/6 of shear correction coefficient in the shear stresses of thick functionally graded material (FGM) magnetostrictive shells, because the material properties of FGMs continuously change across its thickness; also the shear correction coefficient value usually varies with its total thickness and environment temperature. The significance of this study is to present the varied shear correction coefficient effects of magnetostrictive layer thickness on the thermal vibration of FGM shells by using the generalized differential quadrature (GDQ) computation, because the applications and usages of FGMs are widely in the fields of aerospace, automotive and shipbuilding industries. There are many researchers who studied thick FGM shells by considering the effects of transverse shear deformation, and the literature reviews are listed according to the publication year. In 2014, Mantari and Guedes Soares [1] provided the numerical bending results of FGM shells with the sinusoidal higher order shear deformation theory (HSDT). This is unavailable and the theory derived by using the proper choices of shape functions, with tangential stress-free boundary conditions and correction factor is not required for the bending analysis of FGM shells. In 2014, Su et al. [2] used the Ritz method to investigate the free vibration of FGM spherical shells with first-order shear deformation theory (FSDT). The constant value 5/6 of shear correction factor is used in the calculations of transverse shear force resultants. In 2014, Jin et al. [3] used the Haar wavelet method to compute the free vibration solutions of FGM cylindrical shells with FSDT. Until then, it was still an unsolved issue to find the true value of shear correction factor; so the constant value 5/6 is selected and used. In 2014, Su et al. [4] presented the Rayleigh–Ritz method to calculate the free vibration of FGM cylindrical, conical shells with FSDT. It is difficult to obtain the computed, accurate value of the shear correction factor, so constant value 5/6 is selected and used. In 2014, Jung and Han [5] used the finite element method (FEM) with FSDT to calculate the transient results for the FGM shells. The Reissner value of 5/6 is assumed for the shear correction factor. In 2013, Ghannad et al. [6] applied the matched asymptotic method (MAM) of the perturbation theory to obtain an analytical solution for FGM cylindrical shells with FSDT under internal pressure. The shear correction factor value 5/6 is assumed and embedded in the shear stress term for the static state. In 2012, Malekzadeh and Heydarpour [7] used the differential quadrature method (DQM) to calculate and investigate the free vibration of rotating FGM cylindrical shells with FSDT in thermal environment. The parameter of shear correction factor 5/ (6-Poisson's ratio) is assumed and chosen in the DQM numerical computations. In 2012, Zhang et al. [8] used Galerkin's method to obtain the numerical dynamics results for the FGM circular cylindrical shell with FSDT. The value 5/6 is assumed for the shear correction factor introduced by Kadoli, Ganesan and Reddy. In 2010, Daneshjou et al. [9] presented an analytical acoustic transmission solution for FGM cylindrical shells in an external airflow with third order shear deformation

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theory (TSDT). Shear correction factor is not required for the analytical TSDT analysis. In 2009, Sheng and Wang [10] applied the modal analysis technique and Newmark's integration method to compute and found the dynamic behavior of FGM cylindrical shells mounted with piezoelectric PZT layers under moving loads with FSDT. Shear correction factor is not required for the FSDT modal analysis.

The author has some computational experiences of the GDQ method in the composited shells and plates. In 2014, Hong [11] presented the thermal vibration and transient response of Terfenol-D FGM plates by considering the effects of the FSDT model and varied modified shear correction factor. In 2013, Hong [12] studied the rapid heating induced vibration of Terfenol-D FGM circular cylindrical shells without considering the shear deformation effects. In 2013, Hong [13] investigated the thermal vibration of Terfenol-D FGM shells without considering the shear deformation effects. In 2010, Hong [14] presented the computational approach of piezoelectric shells by considering the shear deformation effects. It is interesting to study the varied effects of shear correction coefficient on the thermal vibration of magnetostrictive FGM cylindrical shells by using the GDQ method based on the FSDT. The effects of magnetostrictive layer thickness, control gain values, environment temperature and FGM power law index on the thermal vibration of magnetostrictive FGM thick cylindrical shells are obtained and analyzed. The original contribution of this study might provide a more detailed investigation of varied value effects of shear correction factor on the center deflection and thermal stresses.

2. Formulation

A two-material FGM circular cylindrical shell mounted with outer magnetostrictive layer is shown in Fig. 1 with magnetostrictive layer thickness h_3, FGM material 1 thickness h_1 and FGM material 2 thickness h_2. Young's modulus E_{fgm} of FGM shell is used and expressed in the power-law function as follows [13,15].

$$E_{fgm} = (E_2 - E_1)\left(\frac{z + h/2}{h}\right)^{R_n} + E_1. \tag{1a}$$

where E_1 and E_2 are Young's moduli of the constituent material 1 and 2, respectively, z is the thickness coordinate, h is the thickness of FGMs shell and R_n is the power law index. The other material properties are assumed in the simple average form as follows.

$$\nu_{fgm} = (\nu_2 + \nu_1)/2, \tag{1b}$$

$$\rho_{fgm} = (\rho_2 + \rho_1)/2, \tag{1c}$$

$$\alpha_{fgm} = (\alpha_2 + \alpha_1)/2, \tag{1d}$$

$$\kappa_{fgm} = (\kappa_2 + \kappa_1)/2, \tag{1e}$$

$$C_{vfgm} = (C_{v2} + C_{v1})/2. \tag{1f}$$

where ν_{fgm} is Poisson's ratio, ρ_{fgm} is the density, α_{fgm} is the thermal expansion coefficient, κ_{fgm} is the thermal conductivity and C_{vfgm} is the specific heat of the FGM shell. Subscripts 1 and 2 represent the corresponding properties of constituent materials 1 and 2, respectively.

The time dependence of displacements u, v and w of thick circular cylindrical shells are assumed in the following linear FSDT equations [16].

$$u = u_0(x, \theta, t) + z\phi_x(x, \theta, t), \tag{2a}$$

$$v = v_0(x, \theta, t) + z\phi_\theta(x, \theta, t), \tag{2b}$$

$$w = w(x, \theta, t). \tag{2c}$$

where u_0 and v_0 are tangential displacements, w is transverse displacement of the middle-surface of the shell, ϕ_x and ϕ_θ are middle-surface shear rotations, x and θ are in-surface coordinates of the shell, z is out of surface coordinates of the shell, t is time.

For the plane stresses in the thick FGM circular cylindrical shell, the constitutive equations in the kth layer can be expressed by the membrane stresses, bending stresses and thermal stresses with temperature difference ΔT and magnetostrictive load effects as follows [17,18].

$$\begin{Bmatrix} \sigma_x \\ \sigma_\theta \\ \sigma_{x\theta} \end{Bmatrix}_{(k)} = \begin{bmatrix} \overline{Q}_{11} & \overline{Q}_{12} & \overline{Q}_{16} \\ \overline{Q}_{12} & \overline{Q}_{22} & \overline{Q}_{26} \\ \overline{Q}_{16} & \overline{Q}_{26} & \overline{Q}_{66} \end{bmatrix}_{(k)} \begin{Bmatrix} \varepsilon_x - \alpha_x\Delta T \\ \varepsilon_\theta - \alpha_\theta\Delta T \\ \varepsilon_{x\theta} - \alpha_{x\theta}\Delta T \end{Bmatrix}_{(k)} - \begin{bmatrix} 0 & 0 & \tilde{e}_{31} \\ 0 & 0 & \tilde{e}_{32} \\ 0 & 0 & \tilde{e}_{36} \end{bmatrix}_{(k)} \begin{Bmatrix} 0 \\ 0 \\ \tilde{H}_z \end{Bmatrix}_{(k)}. \tag{3a}$$

And the shear stresses are given as follows.

$$\begin{Bmatrix} \sigma_{\theta z} \\ \sigma_{xz} \end{Bmatrix}_{(k)} = \begin{bmatrix} \overline{Q}_{44} & \overline{Q}_{45} \\ \overline{Q}_{45} & \overline{Q}_{55} \end{bmatrix}_{(k)} \begin{Bmatrix} \varepsilon_{\theta z} \\ \varepsilon_{xz} \end{Bmatrix}_{(k)} - \begin{bmatrix} \tilde{e}_{14} & \tilde{e}_{24} & 0 \\ \tilde{e}_{15} & \tilde{e}_{25} & 0 \end{bmatrix}_{(k)} \begin{Bmatrix} 0 \\ 0 \\ \tilde{H}_z \end{Bmatrix}_{(k)}. \tag{3b}$$

where α_x and α_θ are the coefficients of thermal expansion, $\alpha_{x\theta}$ is the coefficient of thermal shear, $\overline{Q}_{ij}$ is the stiffness of FGM shell. ε_x, ε_θ and $\varepsilon_{x\theta}$ are in-plane strains, not negligible $\varepsilon_{\theta z}$ and ε_{xz} are shear strains, the curvatures of k_x, k_θ and $k_{x\theta}$, respectively, in terms of displacement components and shear rotation are given as follows.

$$\varepsilon_x = \frac{\partial u_0}{\partial x} + z\frac{\partial \phi_x}{\partial x}, \tag{4a}$$

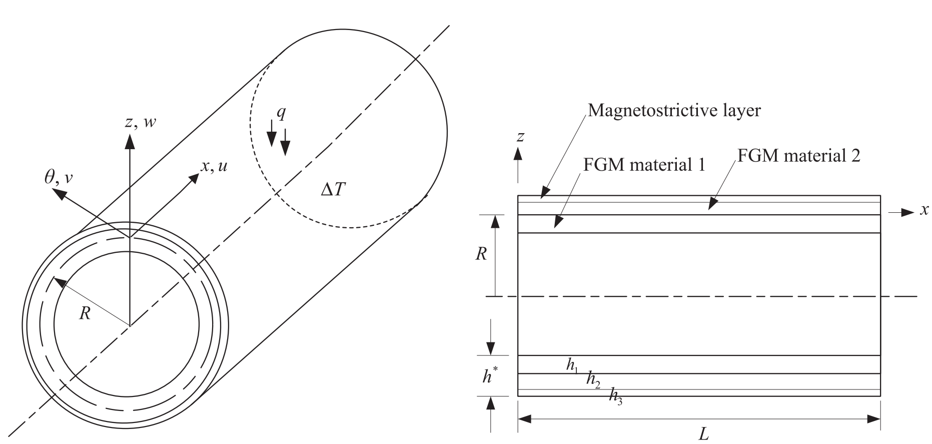

Fig. 1. Two-material FGM circular cylindrical shell with outer magnetostrictive layer.