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Original Research Article

Rapid heating induced vibration of circular cylindrical shells with magnetostrictive functionally graded material

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ABSTRACT

The vibration and transient response of rapid heating on inner surface of the functionally graded material (FGM) circular cylindrical shells with outer magnetostrictive layer is investigated and computed by using the generalized differential quadrature (GDQ) method. The effects of heat flux value, power law index value, environmental temperature value and control gain value on Terfenol-D FGM circular cylindrical shell subjected to two edges clamped condition due to the not very high temperature fluid rapidly flow into the circular cylindrical shells from one side to the end of axial length direction are analyzed. The higher amplitudes of displacement and thermal stress can be obtained under the higher rapid heat flux value. With suitable product of coil constant and control gain value can reduce the amplitudes of displacement and thermal stress into a smaller value. The displacement of Terfenol-D FGM circular cylindrical shell versus the Terfenol-D thickness is stable for all power law index values. The Terfenol-D FGM circular cylindrical shell can stand against the higher temperature of environment with some values of power law index under rapid heating.

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1. Introduction

The material properties of functionally graded material (FGM) usually considered and depended on the temperature of environment. Magnetostrictive material usually applied and controlled to the fields of sensors and actuators. In 2013, Kugler et al. [1] used the low-order shell element numerical method to investigate the beam-shell structures for FGM shells. In 2012, Mollarazi et al. [2] used an axis-symmetric weak form meshless method to analyze the free vibration of FGM cylinders. In 2012, Guz et al. [3] presented the dissipative heating induced vibration analysis for three-layer beam with piezoelectric layers. In 2012, Alibeigloo et al. [4] presented the numerical free vibration analysis for FGM cylindrical shell embedded thin piezoelectric layers. In 2011, Chen et al. [5] used the average stress method to investigate the thermal buckling for ceramic-FGM-metal plates. In 2011, Ootao et al. [6] analyzed and calculated the transient thermal stress for FGM strip composed of piezoelectric and magnetostrictive layers due to non-uniform surface heating. In 2007, Civalek [7] used the discrete singular convolution (DSC) approach method to solve linear vibration problem of isotropic conical shells. In 2007, Civalek [8] investigated the free vibration parameterization of rotating

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laminated cylindrical shells by using the DSC method. In 2006, Civalek [9] presented the free vibration analysis of composite conical shells by using the DSC algorithm. In 2006, Bhangale et al. [10] used the first-order shear deformation theory (FSDT) of finite element method (FEM) to investigate the thermal buckling and free vibration behaviors for FGM conical shells in a high-temperature environment. In 2004, Manoach and Ribeiro [11] presented the nonlinear large amplitude vibrations of moderately thick beams under short heat flux and mechanical harmonic loading. In 2001, Cho and Kardomateas [12] presented a numerical dynamic thermal shock stresses result for a thick orthotropic cylindrical shell due to rapidly change of temperature. In 2000, Wojciechowski [13] presented the controlled purposes development of FGM in mechanical engineering usually composited of particular layers of piezoelectric, magnetostrictive, electrostrictive and shape memory alloys. In 1994, Chang and Shyong [14] used the FEM to compute and find the transient response results for laminated circular cylindrical shell under thermal impact. In 1993, Huang and Tauchert [15] used the FEM to calculate the large-amplitude vibration result for graphite-reinforced aluminum cylindrical panels during a sudden rise in surface temperature. In 1980, Manolis and Beskos [16] used the general numerical method to investigate the vibrations response of beam structures under rapidly thermal loads. In 1982, Shirakawa [17] presented the numerical dynamic responses of displacements and stresses for an orthotropic cylindrical shell due to rapid heating.

In the literature same title problem can be solved via different approach. The main superiority of presented method generalized differential quadrature (GDQ) used to solve the title problem, get acceptable results with less grid and computational time in the not higher modes. Namely, by using the axis-symmetric elements FEM is more effectively used for title problem in the higher modes. The author has some computational experiences and solutions in the piezoelectric shells and magnetostrictive plates by using the GDQ method. In 2013, Hong [18] investigated transient response of stress and displacement for magnetostrictive FGM square plates under rapid heating. In 2012, Hong [19] investigated the stress and displacement of magnetostrictive FGM plates in rapid heating by considering the effects: thickness of Terfenol-D, control gains, rapid heating flux and power law index of SUS304-Si_3N_4 materials. In 2010, Hong [20] computed and presented the solutions of thermal transient response of magnetostrictive plates. In 2010, Hong [21] investigated the behaviors of displacement and stresses of piezoelectric shells under the electromechanical loads. In 2009, Hong [22] investigated and obtained the thermal vibration of axial, circumferential and normal displacements of laminated shells under rapid heating. Usually the FGM shell work is motivated in the higher temperature environment as shielding and might be induced vibration due to rapid heating. A reducing vibration subject of practical solution might be the use of magnetostrictive material layer onto the surface of FGM shells. It is interesting to study the thermal vibration and transient responses of displacement and stress, with and without the effect of velocity feedback, respectively in the magnetostrictive FGM shell under rapid heating due to the not very high temperature fluid rapidly flow into the circular cylindrical shells from one side to the end of axial length direction by using the GDQ method.

2. Formulation

2.1. *FGM*

The Young's modulus is usually in great value of GPa (10^9 N/m^2) unit, so it is the main and dominant properties when compared with others. For the calculation simplification in stiffness integrations of FGM circular cylindrical shell, it is reasonable to assume only the Young's modulus is in the power law function of two-material FGM shell, the others properties are all in the average forms. The Young's modulus for the power law function of two-material FGM circular cylindrical shell as shown in Fig. 1 is expressed in the following equation in 2006 by Chi and Chung [23]

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

$$\kappa_{fgm} = \frac{\kappa_2 + \kappa_1}{2}, \tag{1b}$$

$$\alpha_{fgm} = \frac{\alpha_2 + \alpha_1}{2}, \tag{1c}$$

$$\rho_{fgm} = \frac{\rho_2 + \rho_1}{2}, \tag{1d}$$

$$\nu_{fgm} = \frac{\nu_2 + \nu_1}{2}. \tag{1e}$$

where z is the thickness coordinate, h is the thickness of FGM shells. R_n is the power law index. E_{fgm}, E_1 and E_2 are the Young's modulus, κ_{fgm}, κ_1 and κ_2 are the thermal conductivities, α_{fgm}, α_1 and α_2 are the thermal expansion coefficients, ρ_{fgm}, ρ_1 and ρ_2 are the densities, ν_{fgm}, ν_1 and ν_2 are the Poisson's ratios, respectively to the FGM shells, the constituent FGM material 1 and FGM material 2. The term of properties E_1, E_2, κ_1, κ_2, α_2, α_1, ρ_1, ρ_2, ν_1 and ν_2 can be expressed corresponding to the individual properties term P_i in constituent material equation $P_i = P_0(P_{-1}T^{-1} + 1 + P_1T + P_2T^2 + P_3T^3)$ in which P_0, P_{-1}, P_1, P_2 and P_3 are the temperature coefficients, T is the temperature of environment.

2.2. *Stress–strain relations with magnetostrictive effect*

A thin multilayered of magnetostrictive FGM circular cylindrical shells subjected to rapid heating on inner surface is considered as shown in Fig. 1, the thermo elastic stress–strain relationship of the kth layer (denoted in the subscript (k)) including thermal strain and magnetostrictive coupling effect are expressed in the following equations in 2006 by Lee et al. [24].

$$\begin{Bmatrix} \sigma_x \\ \sigma_\theta \\ \sigma_{x\theta} \end{Bmatrix}_{(k)} = \begin{bmatrix} \overline{Q}_{11} & \overline{Q}_{12} & \overline{Q}_{16} \\ \overline{Q}_{12} & \overline{Q}_{22} & \overline{Q}_{26} \\ \overline{Q}_{16} & \overline{Q}_{26} & \overline{Q}_{66} \end{bmatrix}_{(k)} \begin{Bmatrix} \varepsilon_x - \alpha_x \Delta T \\ \varepsilon_\theta - \alpha_\theta \Delta T \\ \varepsilon_{x\theta} - \alpha_{x\theta} \Delta T \end{Bmatrix}_{(k)} - \begin{bmatrix} 0 & 0 & \overline{e}_{31} \\ 0 & 0 & \overline{e}_{32} \\ 0 & 0 & \overline{e}_{36} \end{bmatrix}_{(k)} \begin{Bmatrix} 0 \\ 0 \\ \tilde{H}_z \end{Bmatrix}_{(k)}. \tag{2}$$

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