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Three-dimensional thermo-elastic analysis of a functionally graded cylindrical shell with piezoelectric layers by differential quadrature method

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ABSTRACT

Three-dimensional thermo-elastic analysis of a functionally graded cylindrical shell with piezoelectric layers under the effect of asymmetric thermo-electro-mechanical loads is carried out. Numerical results of displacement, stress and thermal fields are obtained using two versions of the differential quadrature methods, namely polynomial and Fourier quadrature methods. Material properties of the shell are assumed to be graded in the radial direction according to a power law but the Poisson's ratio is assumed to be constant. Shells are considered to be under the effect of the pressure loading in the form of cosine and ring pressure loads, electric potentials and temperature fields. Numerical results for various boundary conditions are obtained and the effects of the thickness of piezoelectric layers, grading index of material properties and the ratio of the thickness to the radius of the shell on these results is presented.

1. Introduction

Piezoelectric materials have been extensively used in various smart structures as distributed sensors and actuators for active structural control purposes. On the other hand, high load carrying capacities of laminated shells of revolution make them very attractive members for structural applications. Functionally graded materials (FGMs) are composites with material properties varying smoothly in one or more directions which exhibit preferred structural responses.

Several research works have been contributed to model and investigate the basic structural responses of piezoelectric materials i.e. in the pioneering researches of Tiersten [1]. Kapuria et al. [2] presented an exact solution for a finite simply supported, transversely isotropic cylindrical shell subjected to axisymmetric thermal, pressure and electrostatic loading. Heyliger [3] carried out an exact three-dimensional analysis of a laminated piezoelectric cylinder under static loads with simply supported boundary conditions and found the elastic and electric fields of each layer of the laminate, using the Frobenius method. Chen and Shen [4] obtained the exact solution of an orthotropic cylindrical shell of finite length with piezoelectric layers acting as sensor and actuator subjected to axisymmetric thermo-electro-mechanical loads. In their study, the axisymmetric thermal and mechanical loadings were expanded as Fourier series and the power series expansion method was employed to obtain the solution. Shakeri et al. [5] carried out three-dimensional elasticity analysis of laminated cylinders with piezoelectric sensor and actuator layers, subjected to internal pressure loading and uniform electric excitation at the outer surface employing the Galerkin finite element method.

A numerical analysis of piezoelectric strip under the effect of symmetric pressure and voltage on the upper and the lower edges with traction-free boundaries using the generalized differential quadrature method is presented by Hong et al. [6]. Shao et al. [7] carried out an analytical stress analysis of a functionally graded hollow cylinder of finite length and simply supported boundary conditions subjected to pressure loadings on the inner and outer surfaces. They assumed that thermo-mechanical properties of functionally graded material to be temperature dependent and vary continuously in the radial direction and employed Laplace transform techniques and series solving method to solve the ordinary differential equation. Ootao and Tanigawa [8] calculated transient thermal stresses in a cylindrical panel made of functionally graded material due to a nonuniform heat supply by analytical method. Tutuncu [9] obtained stress and displacement fields in thick walled cylinders made of functionally graded materials with exponentially varying properties subjected to internal pressure, using the power series solution method. Shao and Ma [10] calculated thermo-mechanical stresses in functionally graded circular hollow cylinders subjected to mechanical loads and linearly increasing

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