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Buckling and Free Vibration Characteristics of a Uniformly Heated Isotropic Cylindrical Panel

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Abstract

In this paper buckling and free vibration characteristics of an isotropic cylindrical panel subjected to uniform temperature rise has been investigated using finite element method. The procedure involves the determination of critical buckling temperature, which is followed by modal analysis considering pre-stress due to the thermal field in the cylindrical panel. Detailed studies are carried out to analyze the influence of curvature ratio, thickness ratio and aspect ratio on the critical buckling temperature and free vibration behavior of an isotropic cylindrical panel. It has been found that as the curvature ratio and the thickness ratio increases the thermal buckling strength of the cylindrical panel decreases. It has also been found that free vibration frequencies reduce with an increase in temperature and the reduction is more significant for the lowest frequency mode. It is observed that free vibration mode shapes at ambient temperature changes with an increase in temperature.

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Keywords: Cylindrical Panel; Buckling temperature; Free vibration; Finite element method.

1. Introduction

Cylindrical shell possesses high load-carrying capacity, very high stiffness and containment of space and hence plays an important role in many engineering structures. Thin cylindrical shell structure used in the aircraft, missile and high speed aerospace vehicles are subjected to aerodynamic heating which induces a temperature distribution over the surface. These structural members are slender in nature and sensitive to the thermal loads. The main importance in the prediction of mechanical behavior of such structures are they have been employed in thermal working environment. For example, structures with curved shape used in rockets and hypersonic airplane are under high temperature working environment. In certain cases, the thermal load plays an important role in deciding and controlling the design. Thermal stresses developed due to elevated temperature will lead buckling failure of these slender structural members. The

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dynamic behavior of the heated panel members will be significantly influenced by the thermal stress developed because of thermal load. Several researchers have analyzed the buckling of cylindrical panels under thermal load. Jeng-Shian and Wei-Chong [1] studied the thermal buckling analysis of antisymmetric angle-ply laminated cylindrical shells that were simply supported and subjected to a uniform temperature rise by using a finite element method based on the higher order displacement functions. It was found that that first order theory overestimates the thermal buckling temperature of the shell. Finite element method was used by Aubad [2] to estimate the thermal buckling of multi-layered composite spheroidal spherical shells with clamped boundary condition under uniform distribution thermal load. It was found that the critical buckling temperature of the panel is highly influenced by the spherical angle, fiber orientation, number of layers of composite shell and radius to thickness ratio. Thermally-induced large-deflection behaviors of laminates, including flat plates and cylindrical and doubly-curved panels was investigated by Huang and Tauchert [3] using a finite element technique, based on the first-order shear deformation theory. Shahsiah and Eslami [4] determined the critical thermal buckling loads for a functionally graded cylindrical shell subjected to uniform temperature rise and radial temperature difference under simply supported boundary conditions. Derivations were based on the first-order shell theory, the Sanders kinematic relations, and the Donnell stability equations. Rao and Ganesan [5] used finite element method to analyze the free vibration behavior of isotropic plates immersed in hot fluids. Where it was concluded that when the plate is exposed to elevated temperature, its natural frequency reduces with increase in temperature. Buckling and free vibration characteristics of isotropic plates under arbitrarily varying temperature distributions was investigated by Jeyaraj [6] using finite element method under different boundary conditions. It was found that anti-nodal position of the fundamental buckling mode appears away/near to the free edge when the free edge was exposed to minimum/maximum temperature of the variation. Very few researchers investigated the free vibration behavior of panels subjected to thermal load. Ganapathi et al. [7] has investigated the dynamic analysis of laminated cross-ply composite non-circular thick cylindrical shells exposed to thermal/mechanical load based on higher-order theory. Finite element approach in conjunction with the direct time integration technique has been used to obtain shell responses. Buckling and free vibration analysis of functionally graded cylindrical shells subjected to a temperature-specified boundary condition was studied by Kadoli and Ganesan [8] by using first order shear deformation theory. Bailey [9] analyzed the free vibration and buckling of a double wedge square cantilever plate under uniform temperature rise. The magnitude of the thermal load at which the frequency of the particular mode vanishes gives the critical buckling temperature for that mode.

The literature survey reveals that a detailed investigation of combined buckling and free vibration behavior of a uniformly heated cylindrical panel has not been carried out. In the present work, buckling and free vibration behavior of isotropic cylindrical panels under uniform thermal load have been studied and analyzed by commercially available finite element software ANSYS. A computer code has been developed in APDL for isotropic cylindrical panel. The free vibration response of the present model under uniform thermal load is obtained using the Block Lanczos method. Further, the effects of different structural parameters, namely the thickness ratio, curvature ratio, aspect ratio and critical buckling temperature on the free vibrational behavior of the cylindrical shell panel was examined so that these parameters can be modified in the design stage to yield desired vibration responses.

2. Analysis approach

2.1. Finite element analysis

Finite Element Method (FEM) has been used to analyze the critical buckling temperature and the effects of thermal load on the natural frequencies and its corresponding mode shapes of an isotropic cylindrical panel. The model has been discretized using an eight node isoparametric shell element (SHELL281), available in ANSYS library. It consists of an 8-noded element having six degrees of freedom at each node: translation in and rotation about the x, y and z-axis Figure 1(a). It can be used to analyze thin to moderately thick shell structures.