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An investigation of dynamic behavior of the cylindrical shells under thermal effect

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ABSTRACT

Study the vibration characteristics of the cylindrical shell is considered a very important issue, because of the cylindrical shells are used for different applications in engineering fields such as missiles, electric motors, rocketry, etc. In different applications, the cylindrical shells have produced a high level of noise and vibration that effect on the behavior and performance of the systems. In some cases, when those systems work under these conditions for enough time, this will lead the systems to failure or at least change the situation of those systems from stable zone to unstable zone. In this paper, the finite element method was used to investigate deeply the vibration characteristics of cylindrical shells under different surrounding temperatures. Furthermore, the effect of thickness on the dynamic characteristics was investigated.

1. Introduction

A circular cylindrical shell is an essential element in different fields of engineering applications such as aircraft, locomotive, gas turbines and many other systems possess one piece or more of a circular cylindrical shell. The domain of vibration principles compact with the action of vibrating systems. The flexural vibration and fatigue fracture of a circular cylindrical shell working under the thermal effect becomes a very interesting subject in mechanical engineering design. The cylindrical shells may appear in different application such as missiles, storage tanks, and pressure vessels. All these applications require intensive study in both static and dynamic analysis.

Therefore, it's necessary to investigate the factors that affected the material properties (e.g. modulus of elasticity) and stiffness of the system and eventually how these factors will effect on the dynamic characteristics of the system. On the other hand, find out the effect of changing in the material properties and the stiffness on the behavior and performance of the system. Most of the studies about the cylindrical shell relevant to find the effect of dimensions (thickness and length) on the natural frequencies, but there are very seldom researchers studied the thermal effects on the vibration characteristics of the cylindrical shell.

Ahmadian and Bonakdar [1] applied the finite element method to find the solutions of the static and modal problems of laminated hollow cylinders. The super-element was used in their analysis consist of 16 nodes and each node has 6 degrees of freedom. Different external loads were subjected to assuming different working conditions. The results proved that the model was reliable and the percentage error was acceptable.

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Li and Lam [2] investigated the frequency characteristics of the rotating cylinder shell using the generalized differential quadrature method (GDQ). Their studies based on Love-type shell theory to transform the three dimensional dynamic problems to one dimensional which is the meridional direction. Furthermore, the influences of rotating speed on the correlation between the wave number in the circumferential direction and the frequency; their results had a good agreement with other researchers that used different methods.

Loy and Lam [3] investigated the impacts of the tension which occurred at the initial time, centrifugal force and Coriolis on the dynamic behavior of the thin cylindrical panels (rotating). The Eigen-solutions are obtained by using the Newton-Raphson method to carry out their analysis. They found that the behaviors of natural frequencies of thin cylindrical panels (rotating) are like those which appeared in the rotating cylinder shell. The results proved that the proposed approach was valid.

Guo et al. [4] used nine-nodes super-parametric element to build the finite element model in order to study the vibration of rotating cylindrical shells, they took into consideration the effects of initial tension and its effect on the nonlinear geometry because of large deformation Coriolis acceleration, Centrifugal force. Also, they investigated the effect of rotation in three dimensions modes of the cylindrical shell.

Popov [5] presented the developed model to explain how the dynamic loads affect the buckling and the vibration status of the shells under parametric excitation assuming the bifurcation and dynamics nonlinearity. He spotted light on the nonlinearities which existed in geometry that affect the vibrations of circular cylindrical shells and he concluded that the linear theory will not suitable to obtain accurate results when the amplitude becomes comparable to the thickness of the shell.

Ng and Lam [6] studied the effects of constant axial loads on the vibration and critical speed of thin isotropic cylindrical shells applying Donnell's theory. The effects of both of the centrifugal and Coriolis forces were taken into consideration.

Tafreshi [7] formulated a model to compute the delamination in isotropic and laminated composite cylindrical shells using the numerical technique (finite element method) with combined of single and double layers. The effects of the delamination size, orientation and through-the-width position with a series of laminated cylinders were investigated. The change in properties of the materials was taken into consideration in the mathematical model.

Omer Civalek [8] built different mathematical models of rotating shells (conical shape) working in different working conditions and then applied the discrete singular convolution method to analyze the vibration characteristics of these shells.

Saito and Endo [9] applied the equations of the Flüₓgge's to find the vibration characteristics of the finite length of rotating cylinder shell. They took into consideration the initial tensions which occurred due to the rotation in the cylinder shell. Three types of boundary conditions were assumed using Galerkin's method to analyze the frequencies during the traveling waves. The boundary conditions included the full clamped, the simply supported without axial constraint and the simply supported with axial constraint. The conclusions of this study proved that the frequencies were a function of the rotational speed and considerably affected by the restriction conditions.

Xuebin [10] developed a method based on Flüₓgge's shell theory equations to calculate the free vibration frequencies of the thin circular cylindrical shell assuming the materials were orthotropic. This work focused on the coupled polynomial eigenvalue problem and the results had a good agreement based on the comparison between the classical dynamics approach and the developed one.

Leu [11] studied the effect of strain-hardening visco-plastic on the dynamic behavior of the rotating hollow cylinders using the sequential limit approach. The analytical solutions of the dynamic problem included angular speeds (less than a certain value) were derived. The results of the rigorous which located upper bounds agreed with cases of the limit of angular speeds that calculated using the analytical solution.

Liew et al. [12] explored the stability status according to the dynamic issue of the rotating cylindrical shells under the steady-state and when applied the periodic axial forces using a combination of Bolotin's (1st approximation) and Ritz methods. The solutions of the system of equations (Mathieu–Hill) were presented based on Ritz energy to minimize magnitude. The work included the effects of the hoop tension and Coriolis effects due to the rotation.

The buckling and free vibration analyses of the laminated hat-stiffened shallow were investigated by Prusty [13] using finite element method. The solutions were found for the different design of the stiffeners such as 'T' section and hat shape. The results approved that the stiffened panels showed superior performance compared with the open section stiffeners.

The objective of this research paper is to investigate the dynamic characteristics of any structure under different boundary and load conditions using finite element technique. Where there are many researchers investigated the effect of rotating and damage on the dynamic behaviors of structures [14–18], but a few researchers investigated the thermal effect.

In this work, the mathematical model of a cylindrical shell was developed taking into account the thermal effect of the surrounding on the dynamic characteristics. The general finite element program has been built using Fortran90 Language to compute the frequencies and mode shapes of the cylindrical shell under different boundary condition. A wide range of surrounding temperature (between − 200 °C and 200 °C) was assumed to investigate the change in the natural frequencies of the cylindrical shell due to the thermal effect.

2. Finite element formulations

The superparametric shell element was selected to build the finite element model of the cylindrical shell. FORTRAN90 has been used to build a specific program to investigate the vibration characteristics of the cylindrical shell. The selected element consists of eight nodes with 5-degrees of freedom for each node. The development and applications of isoparametric elements family were presented by Zienkiewicz [19]. This section presents the equations which used to find the stiffness and mass matrices of the superparametric shell element. General displacements vector at any node in the structure using shell element according to the global