

Free Vibration Analysis of Laminated Composite Cylindrical Panel Using ANSYS

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ABSTRACT: Laminated composite cylindrical panels have a variety of applications in engineering field. One of the aeronautical applications is the engine fan case in an aircraft which undergo vibrations from the unbalanced rotor. Free vibration analysis of thin laminated composite cylindrical panels is based on First order Shear Deformation Theory (FSDT) which includes transverse shear deformation in the displacement field. In this paper, free vibration behaviour of laminated composite cylindrical panels is investigated using commercially available software ANSYS. An eight noded isoparametric element is used for the discretisation of the proposed model. The effects of various parameters such as radius to side ratio, side to thickness ratio and different laminates on the free vibration responses are studied.

KEYWORDS: Free vibration, composite cylindrical panels, natural frequency.

I. INTRODUCTION

The recent need for structures with low self weight, high stiffness and durability has increased the demand for composite materials. The composite cylindrical panels are extensively used in many modern engineering structures in aerospace, hydrospace, aircraft, automobile, missile, petrochemical and building industries. As the curved panels are frequently subjected to vibration in a wide range of applications, the study of their vibration behaviour is essential. Few analytical and numerical studies have been made on such panels. The exact solutions to free vibration problems of cylindrical panels are mathematically involved and, in many cases, not available. Hence, most of the available solutions are based on approximate methods, the most commonly used method being the finite element analysis. Sabir et al. [7] had used the strain-based finite element method to carry out a large deflection analysis of isotropic cylindrical shells. Reddy et al. [6] developed higher-order shear deformation theory for elastic shells of orthotropic layers. Lam [5] established analytical solutions for the free vibrations of thick symmetric angle-ply laminated composite cylindrical shells using the first order shear deformation theory (FSDT). Srinivasa et al. [1] carried out experimental and finite element studies on free vibration of laminated composite cylindrical panels and natural frequencies were determined using CQUAD8 finite element of MSC Nastran, and experimental results was compared with those of the finite element solution.

In the present study, a finite element model of laminated composite cylindrical panel of engine fan case in aircraft under free vibration is developed using commercial finite element package ANSYS.

II. THEORY AND FORMULATION

The model has been discretised using an eight noded isoparametric Serendipity element (SHELL281), available in ANSYS library, having six degrees of freedom (three translation about x, y & z axis and three rotations about x, y & z axis) at each node. The free vibration response of the present model is obtained using Block Lanczos method environment based on inbuilt FSDT. The sample model is examined for convergence and then the present results are compared with the available literatures for validation purpose. The displacement field based on FSDT is assumed as follows (Huseyin [4]):

$$u(x, y, z) = u_0(x,y) + z\theta_x(x,y)$$

$$v(x, y, z) = v_0(x,y) + z\theta_y(x,y) \quad (1)$$

$$w(x, y, z) = w_0(x,y) + z\theta_z(x,y)$$

where u, v and w denote the displacements of any point on the panel along (x,y,z) coordinate axes. In equation 1, u_0, v_0 and w_0 are the displacements of the mid-plane, θ_x, θ_y and θ_z are the rotations about the respective axes. The displacements u, v and w can be expressed in terms of shape functions (N_i) as: (Ganapathi et al. [2]).

$$\delta = \sum_{i=1}^j N_i \delta_i \quad (2)$$

where, $\delta_i = [u_{0i} \ v_{0i} \ w_{0i} \ \theta_{xi} \ \theta_{yi} \ \theta_{zi}]^T$

The free vibration analysis involves determination of natural frequencies from the condition:

$$([K]-\omega^2 [M]) \{\delta\} = 0 \quad (3)$$

where, $[K]$ & $[M]$ are the stiffness and mass matrix respectively.

As the first step, the geometry of the cylindrical panel with the desired material properties is created in the ANSYS 14.5 environment using APDL code. The model is then discretized into the required mesh configuration using the eight noded isoparametric Serendipity element (SHELL281) from the ANSYS element library. Further, the model is subjected to desired boundary conditions in order to constrain its degrees of freedom at all the nodal position of the edges. Finally, free vibration analysis of the present model is carried out by Block Lanczos method in ANSYS 14.5 environment based on inbuilt FSDT.

III. RESULTS AND DISCUSSION

Numerical results and validation:

A general composite cylindrical panel model is shown in Fig. 1. The same panel is modelled using the APDL code of ANSYS software as per Srinivasa et al. [1] with the dimensions: $a = 100$ mm, $b = 40$ mm, total thickness of the laminate, $t = 2$ mm, panel angle, $\phi = 60^\circ$ and the number of layers is 20 and the laminate stacking sequence used is antisymmetric angle-ply $[+90^\circ/-90^\circ/.../-90^\circ]$. Its material properties are defined as: $E_1 = 38.07$ GPa, $E_2 = E_3 = 8.1$ GPa, $\rho = 2200$ kg/m³, $G_{12} = G_{13} = G_{23} = 3.05$ GPa, and $\nu_{12} = 0.22$.

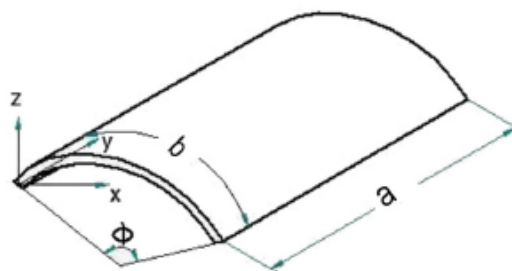


Fig.1. Geometry of the cylindrical panel with dimensions.

The validation check for the eight-node isoparametric curved shell finite elements (SHELL 281) of ANSYS is made by comparing the non-dimensional fundamental frequency coefficient (K_f) values obtained in the present work with those of the literature.

The results of the present work for validation are presented in Table 1, given below in the form of non-dimensional frequency coefficient K_f defined as $K_f = \omega R \sqrt{\frac{\rho}{E_2 t^2}}$, where, ω is natural angular frequency of panel in radian/second and R is panel radius, for laminated composite cylindrical panels and compared with reference [1].

Table 1. Comparison study between current results and that of the reference [1]

Laminate stacking sequence	Non-dimensional frequency coefficient (K_f)			Percentage variation
	Mode Number	Present	Reference[1]	
Angle-ply [+90°/-90°/.../-90°]	1	0.0693	0.068	1.91
	2	0.0881	0.087	1.26
	3	0.1665	0.165	0.909

The main application considered for the free vibration analysis of laminated composite cylindrical panel is from aircraft engineering. An Engine Fan Case of Aircraft which undergoes vibration from the unbalanced rotor is taken for actual analysis. The dimension of Engine Fan Case cylindrical panel is 381 mm in diameter, 10.7 mm thick glass/epoxy, 95 mm in length and total number of ply is 32 with a [0/90/45/-45]_s layup. (Gary et al. [3]). Fig. 2 shows the laminated composite Engine Fan Case of Aircraft. The material properties are defined as: $E_1 = 38.07\text{GPa}$, $E_2 = E_3 = 17.2\text{GPa}$, $\rho = 1716\text{ kg/m}^3$, $G_{12} = 6.89\text{GPa}$, $G_{13} = G_{23} = 4.14\text{GPa}$, and $\nu_{12} = 0.14$.

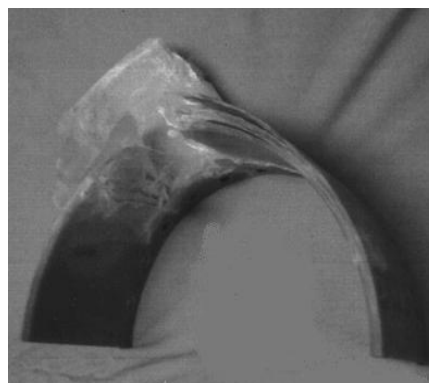


Fig.2. Laminated composite cylindrical Engine Fan Case.

Table 2. Non-dimensional natural frequency (K_f) with increasing values of no. of layers for different lamination schemes

Laminate stacking sequence	Non-dimensional frequency coefficient (K_f)			
	No. of layers			
	8	16	24	32
$[0/90^\circ/45^\circ/-45^\circ]_s$	0.01721	0.01595	0.01569	0.01561
$[+45^\circ/-45^\circ/.../-45^\circ]$	0.01405	0.01406	0.014064	0.014067
$[+90^\circ/-90^\circ/.../-90^\circ]$	0.013092	0.01309	0.013089	0.013087
$[0^\circ/90^\circ/0.../90^\circ]$	0.01653	0.01657	0.01658	0.01659

Table 3. Non-dimensional natural frequency (K_f) for different lamination schemes

Laminate stacking sequence	Non-dimensional frequency coefficient (K_f)
$[0/90^\circ/45^\circ/-45^\circ]_s$	0.01561
$[+45^\circ/-45^\circ/.../-45^\circ]$	0.01407
$[+90^\circ/-90^\circ/.../-90^\circ]$	0.01309
$[0^\circ/90^\circ/0.../90^\circ]$	0.01659

Table 4. Non-dimensional natural frequency (K_f) with increasing values of aspect ratio (a/b)

Aspect ratio (a/b)	Non-dimensional frequency coefficient (K_f)
0.25	0.01561
0.5	0.01572
0.75	0.01577
1	0.01579

Table 5. Non-dimensional natural frequency (K_f) with increasing values of radius to side ratio (R/a)

Radius to side ratio (R/a)	Non-dimensional frequency coefficient (K_f)
1	0.01578
2	0.01565
3	0.01559
4	0.01560
5	0.01558

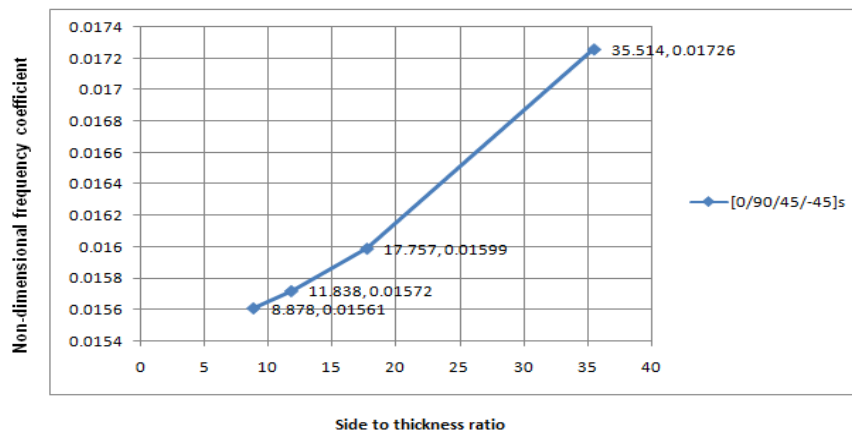


Fig. 3. Variation of Non-dimensional natural frequency (K_f) with increasing values of side to thickness ratio (a/t)

IV. CONCLUSION

The free vibration problem of laminated composite cylindrical panel is analyzed in this study by first order shear deformation theory. The analysis is quite capable of dealing with the vibration problems of composite cylindrical shells with arbitrary end conditions.

The following conclusions are made based on the above study of laminated composite cylindrical panels:

- The experimental values of the first, second, and third natural frequencies agree well with the finite element solution of the sample laminated composite cylindrical panel.
- The non-dimensional frequency coefficient (K_f) for first natural frequency increases as the aspect ratio (a/b) increases.
- It can be seen that as the radius to side ratio (R/a) increases the non-dimensional frequency coefficient K_f value decreases and which is expected for any structural case.
- The non-dimensional frequency coefficient (K_f) increases as the side to thickness ratio (a/t) increases.
- The K_f value for first natural frequency increases for different laminate stacking schemes considered, in the sequence antisymmetric angle-ply $[+90^\circ/-90^\circ/.../-90^\circ]$, $[+45^\circ/-45^\circ/.../-45^\circ]$, symmetric angle-ply $[0/90^\circ/45^\circ/-45^\circ]_s$ and antisymmetric cross-ply $[0^\circ/90^\circ/0.../90^\circ]$.
- For the laminate stacking sequence $[0/90^\circ/45^\circ/-45^\circ]_s$, the non-dimensional frequency coefficient K_f for the first natural frequency decreases with the increase in number of layers and for $[+90^\circ/-90^\circ/.../-90^\circ]$, $[+45^\circ/-45^\circ/.../-45^\circ]$ and $[0^\circ/90^\circ/0.../90^\circ]$ layup, K_f value increases with the increase in number of layers.

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