Analysis of Natural Characteristics of Hard-Coating Damping Thin-walled cylinder shell with FE Method

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Abstract: Based on the theory of elastic mechanics， the natural characteristics of thin-walled cylinder shell structures with hard coating are investigated by finite element method and verified by experiments. For the hard-coating damping thin-walled cylinder shell, the finite element models of anisotropic hard coating and isotropic thin-walled cylinder shell are established. For the thin-walled cylinder shell with and without hard-coating, the numerical analysis and experimental test of vibration characteristics are proceeded to compare and analyze the influence of hard coating on natural characteristics. Besides, the influence of some damping coating parameters, such as cover position, cover area and thickness, on natural characteristics of thin-walled cylinder shell are analyzed. The results indicate that the hard coating could reduce the natural characteristics of thin-walled cylinder shell, and change it by adjusting the cover position and the cover area.

Keywords: Hard-coating damping; Thin-walled cylinder shell; Finite element analysis; Natural characteristics

1 Introduction

For a long time, the study of the vibration characteristics of thin-walled cylinder shell has been a hot topic in mechanics and engineering. For the thin-walled cylinder shell component, the theoretical research on the mechanism and analysis method of vibration damping has many representative results [1, 2], and many successful cases in engineering applications.

The effective methods to study the vibration problem of thin-walled shell structure, such as, the finite element method, the finite difference method and the boundary element method. Dan Guo et al.[3] analyzed the vibration characteristics of the rotating cylindrical shell by finite element method, and compared the influence of large deflection deformation, boundary conditions and rotational speed on the natural frequency and mode of the rotating cylindrical shell. Santos et al.[4] used a semi-analytical finite element model to analyze cylindrical shells composed of functionally graded materials.

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In recent decades, the coating technology for damping vibration becomes the emerging research direction. At present, the damping coating materials mentioned in the related literature mainly include Sn-Cr-MgO, MgO + Al_2O_3, TiN, NiCrAlY, nano-ZrO_2 [5] and so on.

The application of hard coating to damping vibration of the thin-walled cylinder shell structures is a new research hotspot. In this paper, the finite element analysis method of anisotropic composite material is used to simulate the natural characteristics of hard-coating damping thin-walled cylinder shell. The influence of hard coating on the natural characteristics of thin-walled cylinder shell is discussed, and the finite element method is verified by experiments.

2 Finite element modeling of thin-walled cylindrical with hard coating

The thin-walled cylinder shell with hard coating shown in Fig. 1 is chosen to perform the finite element modeling and analysis, and the boundary condition of composite cylindrical shell is clamp-free.

Fig. 1. Hard-coating thin-walled cylinder shell

2.1 Structure parameters

The geometrical parameters and material parameters of the thin-walled cylinder shell are shown in Table 1.

Table 1. Basic parameters of thin-walled cylinder shell

Length L (m)	Mid-surface radius R (m)	Thickness H (m)	Young's modulus E (Pa)	Poisson's ratio μ	Density ρ (kg/m^3)
0.094	0.142	0.002	2.12×10^{11}	0.3	7850

The outer wall of the thin-walled cylinder shell is coated with a hard coat damping material by APS. The hard coat damping material is MgO + Al_2O_3 alloy powder with a mid-surface radius R_2 of 220 mm, a height L_2 of 94 mm and a thickness h_2 of 0.12 mm.

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The input coefficients in the finite element calculation of the anisotropic material matrix of MgO + Al_2O_3 hard-coating damping materials are shown in Table 2.

Table 2. Material parameters of the hard-coating damping

Density kg/m^3	Material parameters of the hard coating C_{ik} GPa				
5300	C_{11}	C_{12}	C_{13}	C_{22}	C_{23}
	183.1	173.2	170.5	183.1	170.5
	C_{33}	C_{44}	C_{55}	C_{66}	
	183.1	45.3	45.3	56.5	

2.2 Finite element model of thin-walled cylinder shell with hard coating

The thin-walled cylinder shell with clamp-free condition is calculated using Solid95 element and the hard coating is simulated using Solid5 element. The finite element model of thin-walled cylinder shell with hard coating is shown in Fig. 2, where the right side is a partial cross-section with 3600 elements.

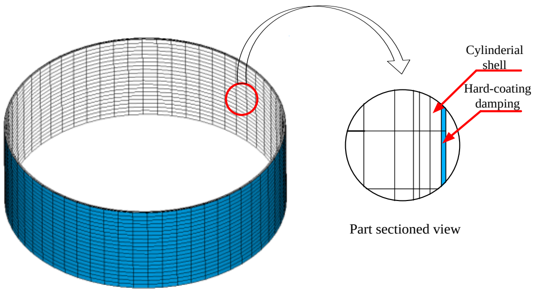


Fig. 2. Finite element model of thin-walled cylinder shell with hard-coating damping

Since the two different elements and different materials adhere the hard-coating damping layer to the thin-walled cylinder shell surface. To mesh the hard-coating thin-walled cylinder shell, the adjacent surface nodes need to be overlapped. So as to satisfy the hypothesis that the displacement of adjacent surfaces in the theoretical analysis is the same. Using the command “EXTOPT”, control the grid number of inner and outer in equal. The clamp-free constraint order for the finite element model is “NSEL, S, LOC, Y, 0; D, all, all”. The vibration modes of first 10 orders are analyzed by the modal expansion method.

2.3 Experimental confirmation of the finite element model

The modal test of the hard-coating thin-walled cylinder shell is carried out to verify the validity of the finite element model and the rationality of the calculation method for the hard-coating thin-walled cylinder shell. The comparison results are shown in Fig. 3.

It is found that the difference of the results obtained by the two methods is small for the thin-walled cylinder shell coated with MgO + Al_2O_3 hard-coating material, which shows that the finite element method and the material parameters are close to the real situation.

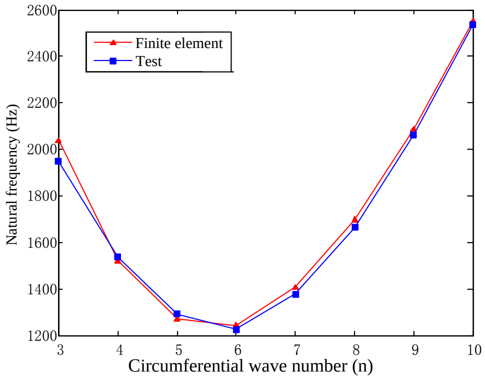
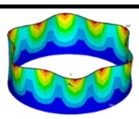
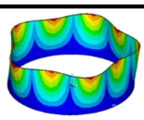
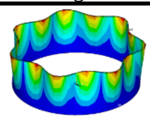
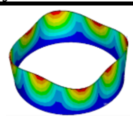
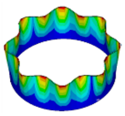
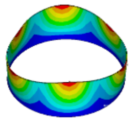
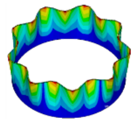
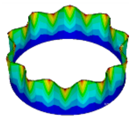


Fig. 3. Natural frequency comparison of finite element calculation and experimental testing

The first 8 orders vibration modes of the hard-coating thin-walled cylinder shell by finite element calculation are shown in Table 3.

Table 3. The first 8 orders vibration modes of the hard-coating thin-walled cylinder shell

Vibration mode				
(m, n)	(1, 6)	(1, 5)	(1, 7)	(1, 4)
Order	1	2	3	4
Vibration mode				
(m, n)	(1, 8)	(1, 3)	(1, 9)	(1, 10)
Order	5	6	7	8

3 Analysis of the effect of hard coating

3.1 Effect of hard coating on the natural characteristics of thin-walled cylinder shell

In order to analyze the influence of the hard-coating material on the natural characteristics of the thin-walled cylinder shell, the natural frequencies obtained by the finite element and the modal test of the thin-walled cylinder shell are compared and shown in Fig. 4.

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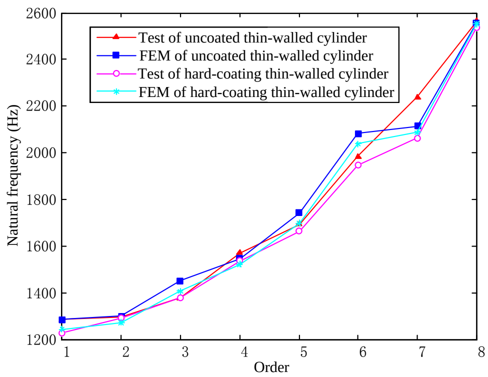


Fig. 4. Comparison of the natural frequencies of thin-walled cylinder shell

It can be seen that the natural frequencies are changed when the MgO + Al_2O_3 hard coating is deposited on the thin-walled cylinder shell. Both the finite element solution and the experimental values of hard-coating thin-walled cylinder shell are lower than the uncoated thin-walled cylinder shell.

3.2 The influence of the coating area and the coating position on the natural characteristics of the thin-walled cylinder shell

In engineering practice, since the requirements of the damping layer of the thin-walled components need to meet the installation process, so there are some restrictions about coating area and coating position of hard coating. The finite element method was used to analyze the hard-coating thin-walled cylinder shell with different coating area and coating position, and the influence on the natural characteristics of the composite cylinder shell.

The finite element model of thin-walled cylinder shell with partial coated hard-coating is shown in Figure 5. The length of the thin-walled cylinder shell is L, the position of both sides of the coating in the column coordinate system (x,θ,z) is $x\in[x_1,x_2]$. By changing the value of x_1 and x_2, the coating position and the coating area of the damping coating is changing. Calculate two conditions as the coating area in 20% and 50%, the results are as follows.

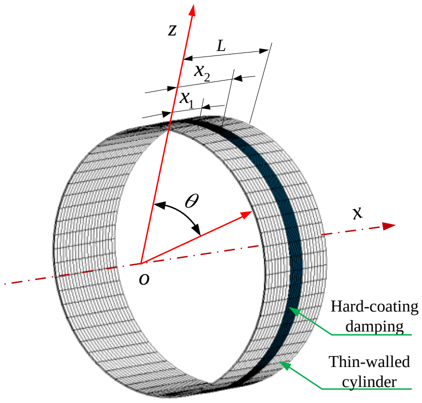
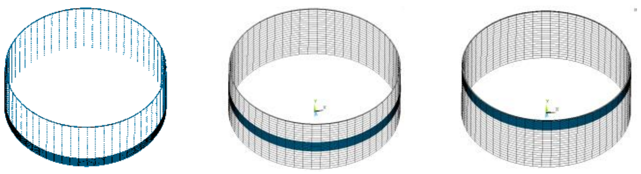


Fig .5. Finite element modal of partial coated hard-coating damping thin-walled cylinder shell

（1）20% hard-coating area

The finite element model shown in Fig. 6 is established, where the coating area is 20% of the thin-walled cylinder shell with the clamped-free boundary condition. In order to verify the influence of different coating positions on the natural characteristics of the thin-walled cylinder shell, the coating position is calculated as the lower part (a), the middle part (b) and the upper part (c). The calculation results are shown in Fig. 7.



(a) Coated lower part (b) Coated middle part (c) Coated upper part

Fig. 6. Finite element modal of thin-walled cylinder shell coated with 20% hard-coating damping

The natural frequency of the thin-walled cylinder shell coated 20% hard-coating damping material is compared with the natural frequency of the thin-walled cylinder shell coated 100% hard-coating material as shown in Fig. 7. The changing trend in the natural frequency of the thin-walled cylinder shell coated 20% hard-coating damping material is similar to the thin-walled cylinder shell coated 100% hard-coating damping material.

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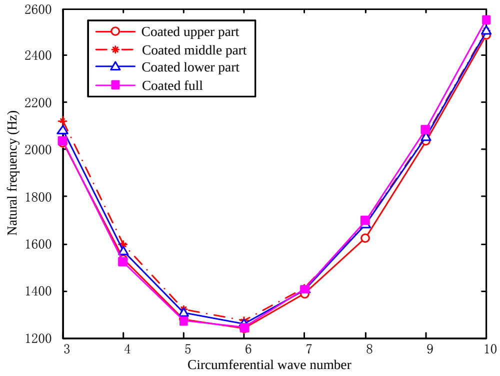
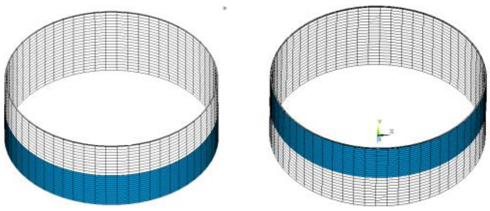


Fig. 7. Comparison of the natural frequency of thin-walled cylinder shell coated 20% hard-coating damping with 100% coating

（2）50% hard-coating area

The finite element model shown in Fig. 8 is established, where the hard-coating damping coating area is 50% of the thin-walled cylinder shell with clamped-free boundary condition. In order to verify the influence of different coating positions on the natural characteristics of the thin-walled cylinder shell, the coating position is calculated as the lower part (a) and the upper part (b). The calculation results are shown in Fig. 9.



(a) Coated lower part (b) Coated upper part

Fig. 8. Finite element modal of thin-walled cylinder shell coated 50% hard-coating damping

The natural frequency of the thin-walled cylinder shell coated 50% hard-coating material is compared with the natural frequency of the thin-walled cylinder shell coated 100% hard-coating material as shown in Fig. 9. The changing trend in the natural characteristics of the thin-walled cylinder shell coated 50% hard-coating damping material is similar to the thin-walled cylinder shell coated 100% hard-coating damping material.

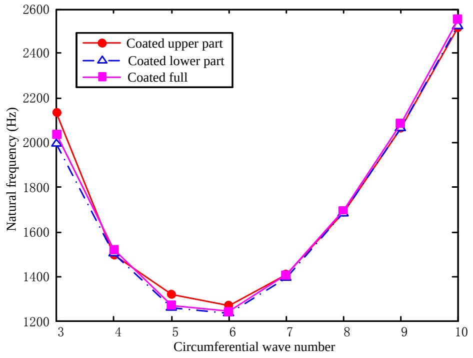


Fig. 9. Comparison of the natural frequency of thin-walled cylinder shell coated 50% hard-coating damping with 100% coating

（3）Influence analysis of coating area on natural frequency in different orders

In order to obtain the relationship between the natural frequency of the hard-coating thin-walled cylinder shell and the coating area, the natural frequency of the thin-walled cylinder shell with 20%, 50%, 80%, 100% of the area and the uncoated cylinder shell are calculated. The different orders of the natural frequency changing curves with the coating area are shown in Fig. 10.

It can be found from Fig. 10, the hard coating reduces the natural frequency of the vibration in different orders. In the case where the frequency of the (1, 5) order with 50% coating, the natural frequency decreases greatly.

The natural frequency of the (1, 7) order changing with the coating area is close to a horizontal straight line, indicating that the natural frequency of the (1, 7) order is less affected by the coating area. The natural frequencies of the (1, 6) and (1, 4) order fluctuate greatly with the changing of the coating area, indicating that the natural frequencies of the (1, 6) and (1, 4) order are affected by the coating area greatly.

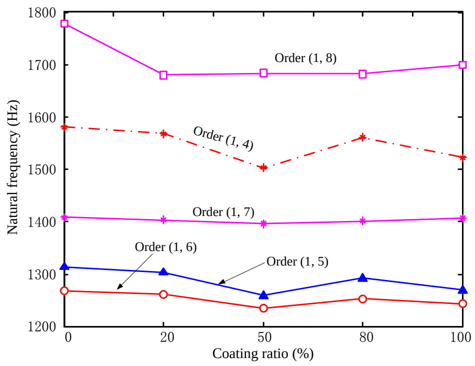


Fig .10. Changing in natural frequency at different coating ratios

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4 Conclusions

In this paper, the finite element method of composite structure is used to analyze the vibration characteristics of hard-coating thin-walled cylinder shell, and the conclusions are as follow:

(1) The modeling method is correct and close to the real situations, the analytical method is accurate.

(2) The hard-coating material has the ability to change the natural characteristics of the thin-walled cylinder shell and the natural characteristics change with the hard-coating coating position and coating area.

References

1. S Sun, D Cao, Q Han, Vibration studies of rotating cylindrical shells with arbitrary edges using characteristic orthogonal polynomials in the Rayleigh–Ritz method, ***International Journal of Mechanical Sciences*** 68 (2013) 180-189.
2. F Zhong, Y Liu, Q Hu, State space method for axi-symmetric bending of variable thickness cylindrical shells, ***Journal of Tsinghua University(Science and Technology)*** 48 (2008) 2021-2024.
3. D Guo, Z Zheng, F Chu, Vibration analysis of spinning cylindrical shells by finite element method, ***Journal of Solids and Structures*** 39 (2002) 725-739.
4. Santos H, Soares C M M, Soares, C A M, Reddy J N, A semi-analytical finite element model for the analysis of cylindrical shells made of functionally graded materials ***Composite Structures*** 91 (2009) 427-432.
5. L Yu, Y Ma, C Zhou, H Xu, Damping capacity and dynamic mechanical characteristics of the plasma-sprayed coatings, ***Materials Science and Engineering: A*** 407 (2005) 174–179.