Application of finite element model building and analysis in aerospace shell structure

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Abstract: Shell parts are widely used in various aerospace products. Whether the design is reasonable will directly affect the product effect. According to the actual structure, the application of ANSYS software to the finite element modeling and analysis of shell parts can provide powerful theoretical analysis and guidance for future structural design. Taking the desulfurization tower as an example, common loads such as gravity load, internal pressure, wind load and seismic load are applied. The stress analysis, strength check and stability check of the desulfurization tower are completed, and the results meet the design requirements.

1. Introduction
Aerospace precision housing parts have the characteristics of compact layout, light weight, and high structural ratio. It is widely used in aerospace bombs, arrows, stars, ships and other products, such as rocket outer shells, engine shells, fairings and other key components [1]. The performance, reliability and other key factors of Aerospace Precision shell parts affect the final performance of products. Due to its thin structure, poor rigidity, complex shape, and large size, the current design of this type of structure mainly relies on engineering experience and lacks strong theoretical analysis and guidance [2-3]. Moreover, the design results and specifications between different structures are not completely applicable, which will greatly affect the safety design and stable operation of shell parts.

Discussing the shell structure design method and analyzing the stress distribution and deformation of each part under the load of different working conditions under normal operation and accident conditions through finite element calculation has very obvious engineering significance and practical value. The desulfurization tower is a large thin-walled shell structure [4], which is very similar to the outer shell of the rocket. This article takes the desulfurization tower as an example, and establishes and analyzes the finite element model of the shell structure through ANSYS software.

2. Finite element modeling
2.1. Geometric model
The desulfurization absorption tower is the main equipment of the flue gas desulfurization process, and it is a large thin-walled cylindrical steel structure. The absorption tower is equipped with support beams and multi-layered forest spraying and defogging devices [5]. The tower body is equipped with flue gas inlet and outlet and pipe holes. The tower body is partially reinforced with section steel. The structure of the entire system is special and complex [6].
The bottom diameter of the desulfurization tower is 6500mm, and the tower height is 50000mm. The lower part of the desulfurization tower is a variable-wall thickness cylindrical barrel, and the upper part is a variable-wall thickness chimney. It is divided into seven cylinder sections, and the wall thickness of each cylinder section gradually changes from 20mm to 10mm. The inlet of desulfurization and increasing flue gas is a square shell structure with a wall thickness of 6mm.

2.2. Finite element model
According to the actual situation and design requirements, the material of the desulfurization tower panel, support beam and reinforced steel is selected as Q235-B, the Poisson's ratio of the material is 0.3, the elastic modulus is 192 GPa, and the linear coefficient is 12.2.

The desulfurization tower model was established using ANSYS. The wall panels, tower top, flue gas inlet, and chimney of the desulfurization tower were modeled by SHELL 181 element, and each supporting beam and reinforced steel were modeled by BEAM 188 element.

Fig. 1 Finite element model of desulfurization tower

The flue gas inlet is of a large opening structure, and a strengthening ring is set at the flue gas inlet, and the mass of the accessory is simulated by a force load. Set UX, UY, UZ, ROT X, ROT Y and ROTZ direction constraints on the ring plate at the bottom of the desulfurization tower.

3. Finite element analysis
Due to the particularity of the structure of the absorption tower, it is usually necessary to use a combination of shell and beam elements when analyzing and calculating it. In the calculation, the loads considered mainly include gravity load, internal pressure, wind load and seismic load. In order to determine the reliability of the finite element calculation of the absorption tower in practical engineering applications, this paper studies the finite element calculation results of various load loading methods.

3.1. Load definition

3.1.1 Gravity load
The weight of the equipment, including panels, reinforced steel and other internal and external components and accessories, as well as the weight of the stored slurry. The gravity load is applied to the entire structure in the form of gravitational acceleration. The density of the entire structure is 7850kg/m³, and the gravity acceleration 9.8m/s².

3.1.2 Flue gas pressure
The flue gas pressure on the upper part of the internal liquid level is in the range of +6kPa~−2kPa, under normal operating conditions: the gas pressure is the internal pressure, and the design pressure P1=+6kPa.

3.1.3 Wind cutting load
According to the provisions of GB50009-2001 "Building Structure Load Code", after finite element modal analysis of the overall model of the desulfurization tower, the vibration period of the
desulfurization tower is obtained as T₁ = -0.88s. The tower adopts the following to consider the influence of wind load: \( \omega_0 = \beta_0 \mu \omega_0 \). The local basic wind pressure is 0.45kN/m², and the wind load is reversible considering two horizontal directions.

3.1.4 Earthquake load

According to the "China Earthquake Parameter Zoning Map" (GB18306-2001), the peak acceleration value of a certain ground motion is 0.05g, and the corresponding basic earthquake intensity is 6 degrees. The design earthquake is divided into the first group, the design characteristic period is 0.45s, and the construction site category is III.

3.2. Stress analysis and stability check

Through the analysis of the load condition of the normal operation of the desulfurization tower, the following two working conditions are selected to carry out the stress analysis of the desulfurization tower.

3.2.1 Working condition 1 (gravity + flue gas pressure)

1) Strength check

The desulfurization tower is under the action of gravity, flue gas pressure (6kPa), ash accumulation and slurry pressure. The maximum primary film plus primary bending stress \( P_L + P_b \) is 75.4MPa, which is located at the flue gas inlet end.

The maximum film stress \( P_L \) is 45.0 MPa, which is at the junction of the wall of the dry tower and the reinforced beam of the flue gas inlet.

The maximum primary film plus primary bending stress is 62.5MPa, which is located at the main connection of the demister support beam and the reinforced section steel of the tower wall.
For pressure parts such as the side wall of the desulfurization tower and the flue gas inlet, the allowable stress is 120 MPa. For non-pressure parts such as support beams and reinforced steel, the allowable stress of the material is 150 MPa. Therefore, the stress of the desulfurization tower satisfies $\sigma \leq 1.2[\sigma]^1$.

2) Stability check

The axial stress that causes instability is mainly caused by mass load and bending moment (caused by wind load and seismic load). The most likely part of instability is the bottom of the tower and the stress concentration near the flue gas inlet and outlet, so the stability is corrected. Nuclear is mainly aimed at the bottom of the tower and the area near the flue gas inlet and outlet.

According to the wall thickness of each barrel section of the desulfurization tower and considering the corrosion allowance and negative deviation of the material, the value of $A$ calculated by the formula $A=0.0946be/Ri$ is calculated according to the material used and the design temperature to obtain the allowable wall thickness of the desulfurization tower. The axial compressive stress is: $B_1=65$MPa, $B_2=57$MPa, $B_3=75$MPa, $B_4=65$MPa, $B_5=55$MPa.

According to the results of finite element calculation, the stability check of each tube section on the desulfurization tower is as follows: The numerical value of $P_L+P_B < B_1$.

3.2.2 Working condition two (gravity + flue gas pressure + 0.25 times X-direction wind load + X-direction earthquake)

Under the action of gravity, flue gas pressure (6kPa), ash accumulation, slurry pressure, 0.25 times X-direction wind load and X-direction earthquake. The largest film plus one bending the stress $P_L+P_B$ is 106MPa. It is located at the junction of the tower wall and the flue gas inlet.

The maximum film stress $P_L$ is 90.2MPa, which is located at the junction of the tower wall and the flue gas inlet. The maximum primary film plus primary bending stress is 84.6MPa, which is located on the reinforced section steel at the junction of the flue gas inlet and the tower wall.

For pressure parts such as the side wall of the desulfurization tower and the flue gas inlet, the allowable stress is 120MPa. For non-compression parts such as support beams and reinforced steel, the allowable stress of the material is 150MPa. Therefore, the stress of the desulfurization tower satisfies: $\sigma < 1.2[\sigma]^1$.

4. Conclusion

In this paper, the finite element analysis software ANSYS is used to establish the desulfurization tower model, divide the mesh, define the boundary conditions, solve and post-process, and obtain the finite element calculation results of various load loading methods, and obtain the cloud diagram of the film stress and bending stress distribution.

According to its stress distribution and allowable stress, the strength check and stability check are carried out. When only gravity and wind pressure are applied, the stress of the desulfurization tower is satisfied $\sigma < [\sigma]^1$. When wind load and seismic load are added, the stress is satisfied $\sigma < 1.2[\sigma]^1$.

The application of ANSYS software to the stress analysis of the desulfurization tower can greatly improve efficiency and reduce costs. If you want to get more realistic and reliable results, you must be
reasonable when modeling, meshing, and applying loads. And if conditions permitting, to reduce the simplification of the model is as much as possible.

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