Structural Optimization Analysis Of Rectification Kettle Based On Elastoplastic Mechanics

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Abstract

Based on the analysis of structural strength by elastic mechanics, there is a large stress singularity due to the discontinuity of the equipment structure, which makes the calculation result not consistent with the actual stress of the equipment. According to the actual design and structure of a distillation reactor, based on the theory of elastic-plastic mechanics, through modeling, meshing, loading and constraint analysis, the stress distribution of distillation kettle is analyzed, and the wall thickness and stiffener structure are optimized. The results show that the calculation results based on elastic plastic mechanics are reliable and the design of wall thickness is smaller than the traditional method. It meets the requirements of ASME VIII-2-2015 "another rule of pressure vessel construction".

Keywords

Elastic plastic mechanics; finite element method; pressure vessel; structural optimization.

1. Introduction

Pressure vessels are widely used in many fields such as machinery, metallurgy, nuclear energy, petrochemical, and aerospace [1]. They are often used in harsh conditions such as high temperature, high pressure, toxic, flammable and explosive. Once they fail, they are prone to group death. The accident. At home and abroad, more research has been done on the design method of pressure vessels. For example, the mechanical properties of pressure vessels are tested by the continuous ball indentation test method [2], and the equivalent stress and plasticity of the total stress at the elastoplastic interface [3] of the pressure vessel are analyzed. The theoretical relationship between the depth of the zone and the factors of reverse yielding and bearing capacity, the influence of the loading path [4] on the plastic instability pressure of the variable strengthening container, the change of the transient state with the brittleness of the pressure vessel material [5], the pressure vessel The corrosion situation [6], the study of the basic phenomena such as the pressure vessel welding pool flow field, welding temperature field and mechanical field, welding deformation and residual stress [7], the practical study of the pressure vessel hydraulic pressure test [8] The limitations of the pressure range, the simulation calculation of the phase change heat storage process of the regenerative vessel [9], the effect of the yield strength and working pressure of the high pressure spherical tank on the reliability of the distillation tower Perform stability check under thermal effect and so on. In addition, the finite element method is used more and more widely in the study of stress and stability of pressure vessels, such as the stability analysis of horizontal containers [12]and ring-ribbed reinforced cylindrical pressure-resistant thin shells and offshore platform pressure vessels. Research on crack fatigue life and so on.

According to the ASME "Boiler and Pressure Vessel Code", Volume VIII-2, 2015 version, the structure of a rectification tank with large internal and external pressure design conditions is discontinuous and the local stress is large. It is based on elastic mechanics and elastics. The plasticity theory is used to analyze the stress distribution characteristics of the rectification kettle by finite element method and optimize its structure. Exploring the application method based on elastoplastic mechanics in pressure vessel design.

2. Theoretical basis of elastoplastic finite element analysis

In this paper, the finite element stress analysis is carried out for the large-opening pressure vessel rectification kettle, and the linear elastic stress analysis of the rectification kettle is carried out according to the relevant guidelines of JB-4732 "Steel Pressure Vessel Analysis Design Standard". However, according to the discontinuous structure in the rectification tank model, there is a phenomenon of stress concentration, etc., and further comparison analysis will be carried out using the elastoplastic method.

The whole structure of the rectification kettle is divided into two parts. The part of the cylinder is S30408, and the part of the saddle is Q235B. In the elastoplastic analysis, the mechanical properties of the material need to be mastered. The S30408 calculated by ASME VIII-2 Appendix 3-D The stress-strain curve is shown in Figure 1.

When stress analysis is performed by elastic stress analysis, it is assumed that the material of the structure always obeys Hooke's law, the stress-strain relationship is linear elastic, and the stress and strain are in one-to-one correspondence; under such assumptions, the calculated stress exceeds the yield limit. It is not the true stress of the structure but the "elastic nominal stress". Only when it is less than the yield limit is the true stress in the structure, so there are certain limitations in the calculation.

The elastoplastic analysis method is a combination of elastic stress analysis and plasticity theory. The real stress-strain curve is used to establish the constitutive model of the material in the calculation process. The nonlinear strain-displacement expression can be used to accurately represent the deformed Really strained.

In the elastoplastic analysis process, the stress-strain relationship of the material is divided into two parts. The stress-strain portion below the yield point is called the elastic part, and the part of the stress-strain after the yield point is called the plastic part, that is, the strain-strength part.

Characteristics of elastic deformation:

The stress and strain are completely linear, and the stress tensor causes the volume to change, and the Poisson's ratio is less than 0.5. Hooke's law and generalized Hooke's law are followed in elastic deformation.

The materials of the rectification tank studied in this paper are S30408 and Q345R. In the plastic analysis, the stress and deformation need to be based on the equilibrium relationship of force, the geometric relationship of deformation and the physical relationship of the material. The nonlinearity of the material is caused by the nonlinearity of the constitutive relation, but it is a small deformation problem like the linear elastic finite element. Therefore, the form of the shape function, the strain matrix and the stiffness matrix are the same. The only difference is that the stiffness matrix is calculated by elastoplasticity.

Balance equation:

The matrix form of the equilibrium equation at any point in the deformation body is:

(point in the Ω domain)

3. Structure analysis of rectification kettle

3.1 Basic structure of the rectification kettle

The basic structure and main dimensions of the rectification kettle are shown in Figure 2. It mainly consists of two upper and lower cylinders. The head is a standard elliptical head. There are two large holes above the upper cylinder, which are respectively 500mm in diameter. Hole and steam outlet with a diameter of 350mm. Openings such as discharge port, condensate outlet, water vapor inlet, feed port and other openings have a maximum diameter of 100 mm. For the whole, smaller openings and nozzles have little effect on the cylinder, but for The effect of stress analysis is small and the calculation time is increased, so only two larger holes are retained during modeling. The lower cylinder is substantially a part of the U-shaped tubular heat exchanger, and one end is welded with an end plate, and the end plate has a U-shaped heat exchange tube, wherein the tube can be expanded and contracted to a certain extent, so when the shell and the U-shaped heat exchange When the tube has a temperature difference, the stress generated is small, so the head tube and the U-shaped heat exchange tube can be omitted when modeling, and the tube pressure can be applied on the outer side of the end plate. In addition, the ribs are welded to the upper and lower cylinders, and the rectification tank is a saddle-type mounting method, and two grooves of steel are welded on the upper and lower cylinders.

The nominal thickness of the large cylinder and the large head of the rectification kettle is 10mm, the nominal thickness of the small cylinder and the small head is 8mm, and the corrosion allowance of the rectification kettle is 0mm. The overall structure of the finite element model is as shown in Figure 2. Modeling in size. According to the characteristics of the symmetrical structure of the distillation vessel and the bearing characteristics, a symmetrical mechanical model can be used for analysis. Using 3D software Pro/E modeling, in addition to modeling the large and small cylinders and the head, the two larger pore structures in the upper part of the rectification tank are retained, and the ribs and channels on the outer surface of the cylinder are used. Modeling, modeling saddle mounts, and assembling.

3.2 Design conditions and loads

It is known from the design data sheet 1 that the shell pressure is 0.2 MPa and the tube pressure is 0.83 MPa in the hydraulic test condition, and the rectification tank is mainly subjected to internal pressure. The design parameters of the analysis are shown in Table 1. The material of the cylinder is S30408, the material of the saddle support is S30408, and the other material of the saddle support is Q235B.

4. Hydraulic test finite element analysis

The hydraulic test pressure conditions of the rectification kettle were analyzed by elastic stress analysis method and elastic-plastic stress analysis method according to the ASME VIII-2 pressure vessel specification.

4.1 Elastic Stress Analysis

Introduce the model of the rectification tank into ANSYS, modify the material's Young's modulus to 2*1011pa, Poisson's ratio to 0.3, and perform mesh division. Select Hex Dominant Method in mesh to adopt hexahedral meshing method. The size is 20mm, as shown in Figure 4, where the number of nodes is 418182 and the number of grids is 98358.

According to the ASME Boiler and Pressure Vessel Code International Specification VIII-2 Pressure Vessel Construction Another rule of the limit analysis, the allowable stress Sm of the cylinder material S30408 is 137 MPa, and the yield limit ReL is 1.5 times the allowable stress. 205.5 MPa.

It can be seen from Fig. 6(b) that the stress concentration of the model due to the discontinuity of the model at the rib is stress singularity, the total stress is 1297.1 MPa, and the linear stress classification must be performed on the maximum stress point. The overall film stress intensity SI at the maximum point is 630.62 MPa, and the material yield limit ReL greater than 0.9 times is 184.95 MPa, and the structural strength does not meet the hydraulic test requirements.

4.2 Elastic-plastic stress analysis

The elastic-plastic stress analysis uses design factors to determine the allowable load on the component. Because it is close to the actual structural behavior, the elastic-plastic stress analysis has a relatively accurate assessment of the plastic collapse of the component compared to the elastic analysis method [15].

Elastic-plastic analysis considers the effects of nonlinearities in the analysis. The plastic collapse load is a total load that causes structural instability. This can be represented by the fact that a small load increment can no longer obtain a balanced solution (ie, the solution no longer converges) [16]. Therefore, when performing the elastic-plastic analysis on the rectification kettle, if the final result can be calculated, the solution obtained is convergent, and the structure satisfies the requirements of the hydraulic test; if no result is obtained, the convergence is not obtained. Solution, the structure does not meet the hydraulic test requirements.

The model of the rectification tank was introduced into ANSYS, and the material curves of S30408 and Q235B were calculated according to ASME VIII-2 Appendix 3-D and imported into ANSYS. The pad material of the barrel and saddle support is selected as S30408, and the other part of the saddle support is selected as Q235B.

The Mesh module is used to mesh the whole rectification kettle. The hexahedral meshing method is adopted. The mesh size is 20mm, and the number of nodes is 419914, and the number of grids is 99827.

According to the load-time combination and load factor of the elastic-plastic analysis, the design conditions need to increase the design load by 2.4 (D + ps + p), where D is the material, the container and the weight of the appendage at the position of interest, including The weight of the container (such as the escalator, platform, etc.), the support (such as the legs, skirts, saddles and ears) and the internals, ps is the static pressure caused by the stacked materials or liquid, p is the specified Design internal pressure and external pressure.

5. Conclusion

The finite element analysis of the rectification kettle was carried out by elastic method and elastic-plastic analysis method. The structural optimization and thinning treatment of the rectification kettle and the finite element analysis of the hydraulic test on the optimized structure were carried out. get conclusion:

(1) The analysis by elastic stress method has certain limitations, and the elastic-plastic stress method is closer to the actual working conditions.

(2) According to the provisions of ASME VIII-2, the rectification tank meets the requirements under hydraulic test conditions.

(3) After optimizing the structure of the rectification tank, it also meets the requirements under hydraulic test conditions.

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