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The Finite Element Analysis of The Strength of The Steel Frame Structure of The Industrial Boiler Roof

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Abstract: In this paper, aiming at the problem that the deformation of the 33000 mm roof steel frame structure of a waste heat boiler is more serious, the deformation, stress, and bending moment of the roof steel frame structure are numerically simulated by ANSYS finite element analysis software. The numerical simulation results show that the maximum deformation of the steel frame structure on the top of the furnace is 8.19 mm, which is much smaller than the displacement allowable value of the top floor of 66 mm. The maximum stress is 146.429 MPa, which is lower than the allowable stress f_y=257MPa of Q235 steel. The bending moment of the steel frame structure is mainly concentrated on the large plate beam, which is located near the drum support. The finite element analysis results of the boiler roof steel frame structure show that the strength and stiffness of the boiler roof structure meet the requirements of the corresponding specifications, and the steel frame structure is safe.

Keywords: ANSYS, Industrial boilers, Steel frame structure, Strength analysis.

1. Introduction

As the main bearing equipment of the boiler, the stability of the steel frame determines the safety and reliability of the boiler. Because the natural vibration period of steel frames increases with the increase of height, such as communication towers, transmission towers, wind power towers, steel frames, and other structures, there will be instability and hidden dangers such as large flexibility and small damping due to their high height. Under the action of the earthquake, strong wind, and other loads, the problems of structural lateral displacement resistance and fatigue damage caused by reciprocating vibration are more prominent, and even the risk of overall structural failure and collapse is caused by local damage [1-3].

The steel structure is light in material and has a strong bearing capacity. Because of its low engineering cost and fast construction speed, it can effectively improve the use efficiency and comprehensive economic performance. Therefore, steel structure is widely used as a support steel frame in boiler support equipment. In foreign countries, the design, development, and production technology of boiler steel frames is mature. However, in China, the research and development and manufacture of boiler support steel frames are relatively late, and the components developed and designed still have the disadvantages of too large and heavy structure size and large steel loss [4]. In recent years, with the construction of many large power stations by the five major power generation groups, the domestic boiler industry has been greatly developed. Based on the existing market conditions, the boiler industry should improve the boiler's own R&D and design capabilities as soon as possible.

As the main supporting part of the boiler, the steel frame needs to bear large loads, such as earthquakes and wind. In order to ensure the safety of steel frames, it is an indispensable part of steel frame design to analyze and check the mechanical properties of steel frames [5]. At present, when the boiler industry uses FEM technology to analyze the safety and stability of steel frames, it mainly starts with static analysis, seismic load response characteristics analysis, and wind load response characteristics analysis.

Finite Element Analysis (FEA) is to simplify complex problems. By discretizing the system into several units, the approximate function in each unit is used to replace the function to be solved in the full solution domain, and each unit area has nothing to do with the whole unit or other units. Therefore, when the finite element method is used to solve the problem, a large number of linear algebraic equations need to be established to solve the numerical solution [6].

At present, given the limited modeling function of CAE software, the general use process of finite element technology is to use the general CAD software with strong design function together with CAE software, that is, to complete the modeling design of complex models in CAD software and then transfer to CAE software. However, this software-switching method is difficult to achieve the optimal design of complex models. NX integrates CAD and CAE functions to realize the seamless connection between CAD and CAE, with high calculation accuracy and can realize the integration of design and optimization. At present, the commonly used CAE software can meet the needs of users in terms of performance, function, reliability, and operating environment. It can help users solve a large number of practical engineering problems and also make outstanding contributions to the development of science and technology and engineering applications [7,8]. CAE software commonly used in steel structures includes NASTRAN, ABAQUS, ANSYS, ADINA, MARC, MAGSOFT, etc.

In this paper, aiming at the problems of large deformation and high disturbance of the boiler body hoisting structure in the installation process of an industrial boiler, the steel frame structure of the boiler is numerically modeled by ANSYS software, and the strength of the steel frame structure is analyzed, which provides technical support for the safe installation of the boiler.

2. Boiler Model

The boiler type can be divided into π type boiler supported by frame steel frame suspension and tower type boiler supported by a tower steel frame. The support plate beam of the steel frame of the frame boiler is located at the top as the main load-bearing component, and the boiler is suspended in the middle of the steel frame: the steel frame of the tower boiler cooperates with the column, the cable-stayed support and the horizontal beam to bear the load together, which is widely used in Europe.

The research object of this paper is a waste heat boiler. The main components of the supporting steel frame include columns, beams, large plate beams, and cable-stayed supports. The geometric structure is shown in Figure 1. The boiler support steel frame belongs to the frame type boiler steel frame. Each structure in the steel frame is welded into each beam and column based on I-beam and channel steel, and the material is Q235-A.F. The total height of the boiler steel frame is 33000mm, and the water supply is heated by natural circulation. The drum is arranged on the top frame of the boiler with a supporting structure, and the suspension device is distributed on four main beams. The specific structure is shown in Fig.2.

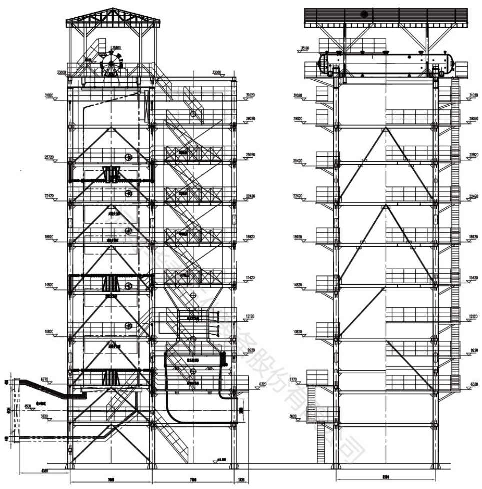

Figure 1. Support steel frame of a waste heat boiler unit.

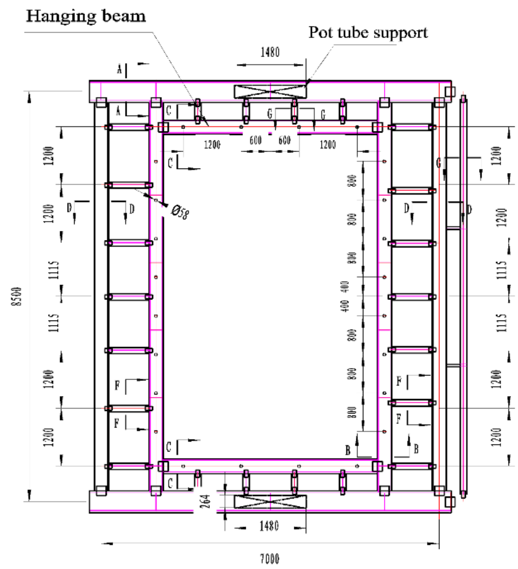

Figure 2. 33000mm furnace roof frame and size.

3. Furnace Top Steel Frame Load

The steel frame mainly bears four types of loads, namely constant load, live load, wind load, and seismic load. The load value of the waste heat boiler is calculated according to the steel frame design standard and the building structure load specification.

1) Constant load (DL)

The boiler top equipment is suspended on the large plate beam through the suspender. The weight of each piece of equipment in the boiler system is the constant load of the steel frame, such as the weight of the furnace auxiliary equipment, the wall insulation layer, and the weight of water, ash, and slag on the steel frame. The constant load value is shown in Table 1.

Table 1. Load condition of waste heat boiler top frame.

Load Name	Load(kg)	Load Distribution
Front membrane wall hanging beam bearing	110000	8 points evenly distributed
Rear membrane wall hanging beam bearing	80000	8 points evenly distributed
Left membrane wall hanging beam bearing	27000	4 points evenly distributed
Right membrane wall hanging beam bearing	27000	4 points evenly distributed
Drum weight	37300	Linear distribution

2) Live load (LL)

Considering the weight of people and equipment during maintenance, and considering the 50-year return period of blood pressure as the basic snow pressure according to the specification, the live load of the steel frame is determined to be LL = 29227N.

3) Wind load (w_k)

The standard value of wind load is calculated according to the load code of the building structure. The calculated wind load of the furnace top frame is shown in Table 2.

Table 2. Wind load value of each node of furnace top frame.

Name	Load (N)
Lateral wind load	12079.6
Forward wind load	19040.8
Backward wind load	15751.6

4. Calculation Model and Boundary Conditions

1) Calculation model and grid division

In ANSYS, the beam element is used to model the roof frame, and then different beams are modeled respectively. The model and grid are shown in Figure 3, and the number of grids is 38564, and the accuracy of the calculation results is independent of the number of grids.

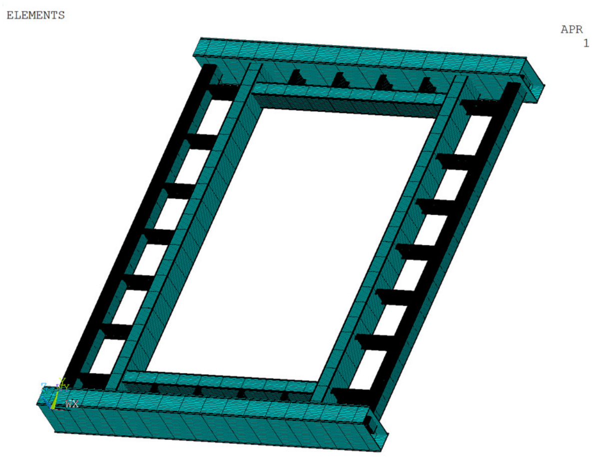

Figure 3. Computational model meshing

2) Calculating boundary conditions

The various loads of the boiler are listed and calculated above. All kinds of loads need to be applied to the calculation model. The combined conditions considering the most unfavorable effects of the project are:

$$S=1.35\times DL+1.4\times LL+1.35\times 0.7\times w_k$$

In order to limit the movement and rotation of the column base joints, the fixed constraint boundary conditions are applied to the contact between the steel frame and the column.

The material of each component is Q235-A.F, and its material parameters are: Young's modulus $E = 2.06E+11$ N/m^2; Poisson's ratio Pr_{xy}=0.3; density ρ=7850kg/m^3.

5. Results and Analysis

Based on the mechanical analysis function of ANSYS finite element software, the stress and displacement of the top steel frame structure under the combination of working condition $S=1.35\times DL+1.4\times LL+1.35\times 0.7\times w_k$ are analyzed.

1) deformation

According to the steel frame design specification [9], the horizontal displacement of the structure should not exceed the allowable values listed in the following table. It can be seen that the allowable value of the top displacement cannot exceed the limit value of H / 500 when the permanent load is applied. According to the calculation, the allowable value of the top level of the structure under permanent load is 66 mm.

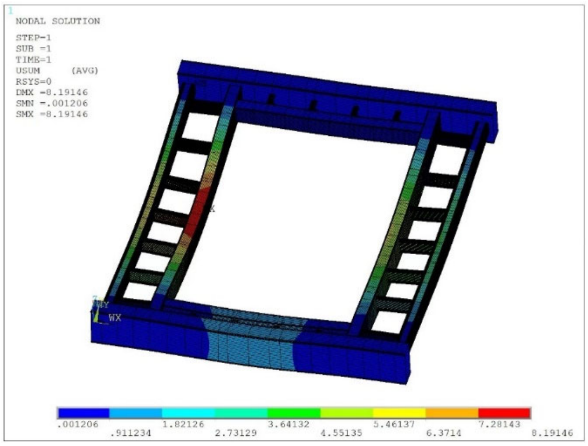

Figure 4. Total deformation of steel frame

Figure 4 is the calculation result of the total deformation of the furnace roof frame. From Figure 4, it can be seen that the maximum deformation of the steel frame structure is 8.19 mm. The maximum deformation occurs at the center of the beam of the front wall of the steel frame, which is the main bearing part at the top of the boiler. The stress concentration point, the deformation caused by the superposition, achieves the maximum amount of deformation. However, the maximum deformation is much smaller than the allowable displacement of the top layer of 66 mm. After the static analysis of the boiler, the displacement check of the top steel frame structure shows that the deformation of the top frame is within the allowable safety range and meets the design requirements.

2) Stress

According to the steel frame design specification, the stress design value of steel should be less than the allowable stress of Q235 steel f_y=257MPa. According to the actual engineering parameters of the boiler, the stress distribution of the top frame shown in Figure 5 is calculated. It can be seen from Fig.5 that the maximum equivalent stress is 146.429 MPa, which is less than the allowable stress. The maximum stress is located at the junction of the steel frame beam.

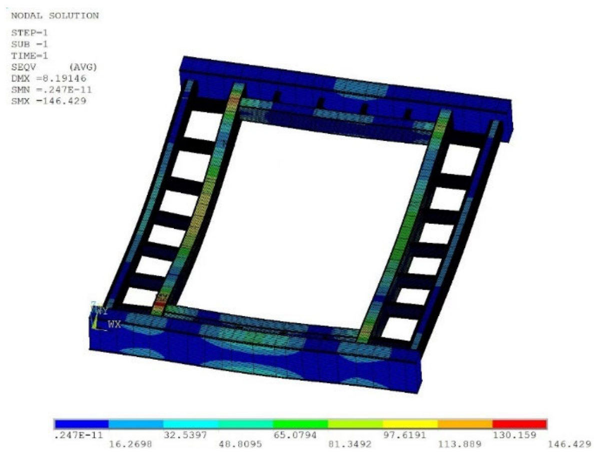

Figure 5. Stress distribution

3) Bending moment

Figure 6 Bending moment distribution of steel frame structure. Figure 6 shows that the bending moment of the two thicker large plate beams is greater than that of the other large plate beams, and the bending moment is mainly concentrated in the drum bracket. The main reason for this phenomenon is that the weight of the drum is much larger than the weight of the steel frame suspension, the load is concentrated, and the two thick plate beams have dense vertical beam support bending stiffness. Therefore, the two large plate beams bear a large bending moment under load.

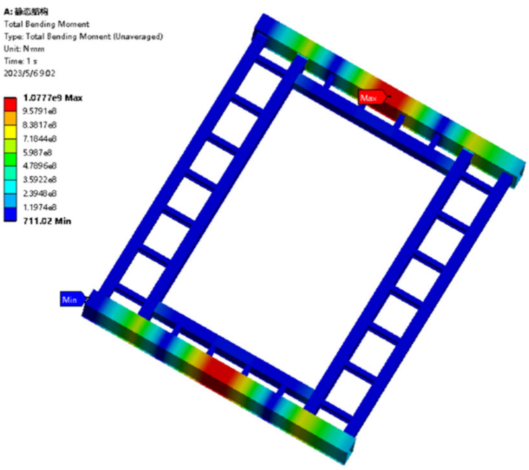

Figure 6. Bending moment distribution

6. Conclusion

1. The load of the roof frame of a waste heat boiler is calculated, and the boiler load under the most unfavorable effect is calculated.

2. The maximum deformation of the frame is 8.19 mm, which is much smaller than the displacement allowable value of the top layer of 66 mm. The maximum stress is 146.429 MPa, which is lower than the allowable stress fy = 257 MPa of Q235 steel. The bending moment of the frame is mainly concentrated on the large plate beam, located near the drum support.

3. The finite element analysis results of the boiler top steel frame structure show that the strength and stiffness of the boiler top structure meet the requirements of the corresponding specifications.

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References

[1] Ding Y, Zhang W, Sun H, et al. Analysis for seismic behavior of tower-type boiler steel structure considering the action of boiler[J]. Journal of Harbin Institute of Technology, 2016.

[2] GB5001 1-2001 Code for seismic design of buildings[M]. 2006.

[3] Green J R. Design of Boiler Steel Structure and its features[J]. Power System Engineering, 1987, 19:895.

[4] Liu Xiaoming, Yang Xiaoxiang, Guo Jingquan, et al. Finite element analysis of steel frame of heat recovery steam generator [J]. Machine Building & Automation, 2012,41(1):65-69.

[5] Chen Xiaoxia. The system of boiler steel frame with fem by I-DEAS [D].Zhejiang University,2007

[6] Amar, Khennane. Introduction to Finite Element Analysis Using Matlab and Abaqus [M]. PUBLISHING HOUSE OF ELECTRONICS INDUSTRY, 2022.

[7] Zhao Zengyao. Finite element analysis is used in engineering machine framework design and optimization [D]. Chan'an University, 2009.

[8] MacNeal-SchwendlerCo. MSC/PATRAN: MSCNASTRAN preference guide: publication no.903009, version 7, July 1997[M].

[9] GB/T 22395-2008 Specification for design of boiler steel structures[M].2008.