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Test, simulation and treatment of the large amplitude sloshing of a 300 MW W-shaped boiler wall

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Abstract: In view of the dangerous condition in which a 300MW "W" type flame boiler has low frequency and large sloshing in its front wall, the peak amplitude and frequency range of vibration are obtained by field vibration test. Based on the finite element ANSYS software, a three-dimensional finite element model of the boiler wall was established by using beam and shell elements and the prestressed modal analysis of the furnace wall was carried out. Compared with the vibration test results, it was found that external excitation frequency and natural frequency were on the beat. It was concluded that the main reason of the vibration was resonance caused by the negative pressure fluctuation and lack of rigidity. Furthermore, considering the characteristics of the full suspension of the furnace wall and avoiding affecting the normal expansion of the wall, a slidable shake stopping device was designed to increase the lateral stiffness of the wall, increasing natural frequency and avoiding the resonance region effectively. The test, simulation and the design idea of the device provide a useful reference for solving the general problem of the shaking of the furnace wall, and have positive significance to prolong the lifetime of the boiler units in stable working conditions.

1 Introduction

There has been a problem of high vibration on the furnace front wall since a W-shaped flame boiler operation. The monitoring results showed that the vibration amplitude of the front wall was different at different elevations, and the largest vibration amplitude was in the middle, reaching 40~50mm. The vibration characteristics of the boiler wall is low frequency, normal, large[1], long-term vibration will cause the related components loose, furnace tube explosion, weld cracking, thermal insulation coating material spalling, and cause a lot of noise. It has great harm to the safe operation and economic benefit of the boiler unit.

The study of boiler vibration in the world began in the early 1950s. In the early stage, the vibration of the tube bundle caused by the Karman vortex, which has made remarkable achievements in theory and practice, can be considered in the design phase. In 1960s, the boiler vibration problem caused by the fluid flowing through the tube bundle has been solved in China [2], but the shaking of the furnace wall caused by the combustion and the dynamic characteristics of the furnace wall has not been paid enough attention.

Liu Fubin and Cao Leisheng [3] made a summary on the reasons of boiler vibration, it is pointed out that the vibration is mainly due to the following four points: fluid dynamics, combustion kinetics, cause resonance, furnace wall rigidity. Fu Feng [4] studied the vibration problem of 300MW "W" flame boiler wall. He analyzed the reasons of vibration of furnace wall from three aspects of design and installation, equipment system and operation, and put forward improvement measures, obtaining some damping effects.

Firstly, the vibration signal was tested to analyze the frequency, amplitude and form of vibration of the furnace wall. And then a three-dimensional finite element model of the furnace wall was established by Ansys to analyze modals after simplifying the model reasonably. At the same time, the vibration test results were compared with the finite element results to get the cause of the vibration of the furnace wall. Finally, a reasonable shake stopping device [5] was designed according to the boiler combustion conditions and structural characteristics to achieve the desired effect of vibration reduction.

2 Vibration test

2.1 Vibration testing principle and layout scheme

The principle of modal test by using vibration test is multiple-input multiple-output (MIMO) Polymax. PolyMax modal identification method belongs to the time-domain identification method of multiple degrees of freedom. It is a kind of multi degree of freedom method to estimate the poles and the participation factor of modes [6].

This test used low-frequency sensors because it was low frequency vibration. Instruments and equipment: Siglab20-42 signal analysis system; 1 DH5927 dynamic signal acquisition equipment; American PCB acceleration sensor; Domestic signal converter; 20m long shielded cable(15); 6m long shielded cable(3); 1 laptop. Vibration test points were mainly distributed in the area of large amplitude according to the field situation. Five test points were arranged on the front of each horizontal rigid beam, and three sensors were pasted on each point.

2.2 Test data and analysis

Take one of them as an example, figure 1 is the acceleration signal spectrum of test point 1 of the first layer (rigid beam), the position of the point is shown in Figure 2. Peak vibration frequency is between 1.5~2.5Hz, and center frequency is about 2.0Hz. For each point, from left to right, this peak decreases gradually. The peak value is larger than -50dB in the point 1 and 2, which has the greatest influence on the whole structure vibration. Another peak frequency is between 3.0~4.5Hz and the peak value increases from left to right.

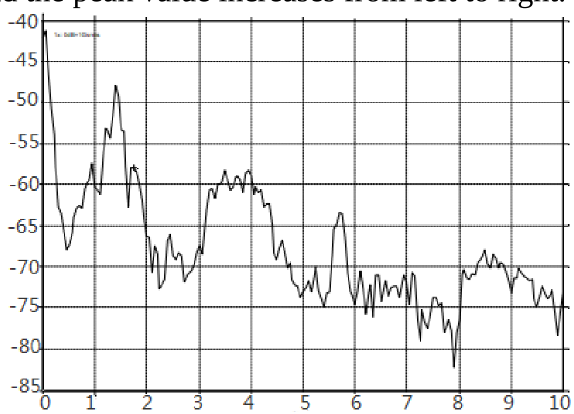

Fig. 1 The spectrum of point 1 in Level 1

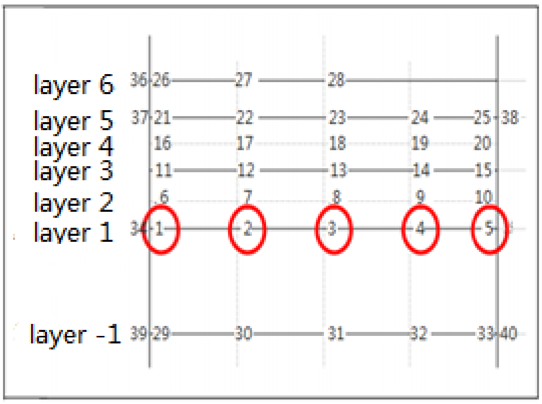

Fig. 2 The position of each point in Level 1

3 Finite element modeling

3.1 Model dimension and material properties

The geometric model of the boiler is composed of rigid beams and front water walls consisting of uniform and variable cross-section tube bundles. The water wall tube material is SA-210C, flat steel material is 20G, and rigid beam material is Q235A. Material property parameter[7]: Density ρ=7.8×10^{3}kg/m^3, Elastic modulus E=207GPa, Poisson ratio v=0.3.The model mainly includes the water wall tube, flat steel and lower header. The front wall is made of water wall tube with a size of 11550mm * 2540mm, and the height of the front wall is 48550mm, the width is 24765mm.

3.2 Element selection, geometric modeling and meshing

The BEAM 189 element is selected for water wall tube and the SHELL 63 element is selected for flat steel. The model ignore some details which don’t affect the dynamic characteristics of the whole structure of the furnace wall, including bolts, steel ingot, blowing system, fire hole, and some other additional parts of the wall. The 1/2 model is created because of the left and right symmetry of the boiler front wall [8], as shown in figure 3.

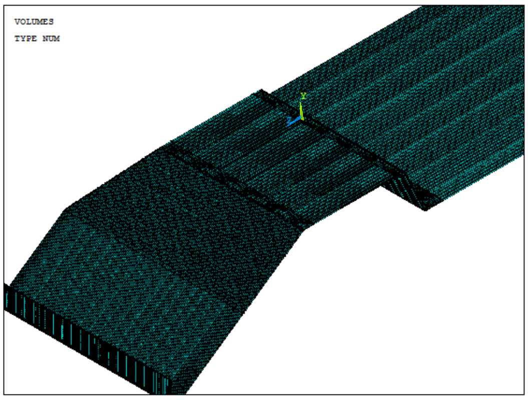

Fig.3 The finite element model of the wall

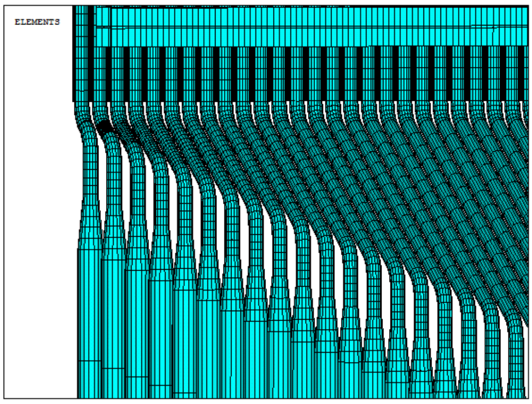

Fig.4 The finite element model of the arch

Because of the large size and complex structure, the modeling process is difficult. As a large number of slender tubes and steel bars were modeled, mesh distortion, enormous calculation and conodes must be avoided when meshing. Variable section tube is meshed by free meshing, and the mesh is suitably encrypted when the force gradient is larger and the shape is discontinuous. The number of elements is 321460 and the number of nodes is 468595 in the final model. The local finite element model of the furnace arch is shown in figure 4.

3.3 Degree of freedom coupling

Since the water wall model is built by two kinds of elements, nodal coupling pairs must be established to achieve the weld connection of flat steel and water wall so that the degrees of freedom of two adjacent nodes are consistent. It should be paid special attention when using the ANSYS coupling command: Node coupling should be carried out in the same coordinate system; the same node is not allowed to appear in multiple coupling; the nodes with other constraints may not be included in the existing coupling. The finite element model of the node coupling is shown in figure 5.

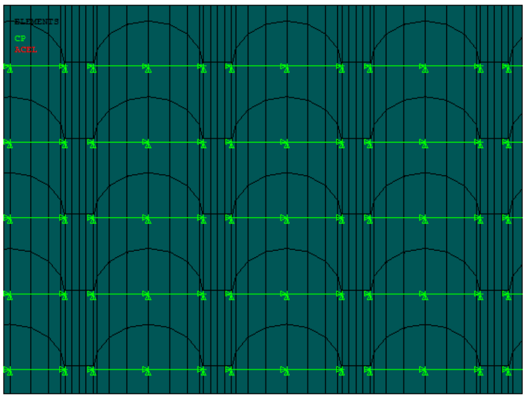

Fig.5 The finite element model for coupling of nodes

4 Modal analyses

The aim of modal analysis is to avoid the resonance frequency of the negative pressure fluctuation and the natural frequency of the furnace wall, which provides a reference for improving the dynamic characteristics of the boiler wall. The modal of boiler front wall is analyzed based on the block Lanczos [9] method of ANSYS.

4.1 Boundary condition

The upper part of the water wall tube is fixed on the upper header. Taking the influence of the boiler thermal expansion into account, the external rigid beam of the boiler is hinged. The front wall and side walls of boiler water wall are connected by flat steels of which stiffness, relative to the outer rigid beam, is very small, so the constraint between them can also be regarded as the hinge.

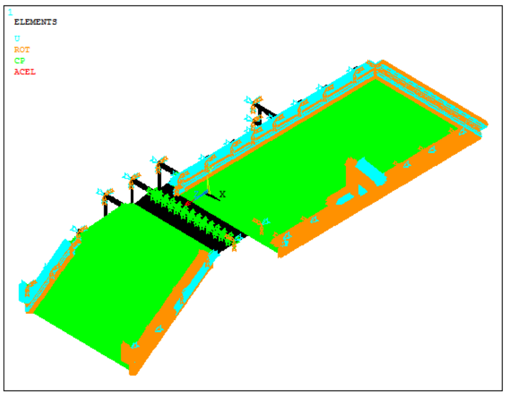

Fig.6 Constraints of finite element model of furnace wall

All the modes obtained by the symmetrical model are symmetrical modes, which leads to the loss of asymmetric modes. Two modes of operation is calculated in order to ensure the mode is not lost at the case of only one symmetry plane, that is, symmetry and antisymmetric constraints are applied on the symmetry plane of furnace wall. Specific constraints are applied as shown in figure 6.

4.2 Result analysis

Because of the huge structure, the influence of the structural stress caused by gravity on the natural frequency of the furnace wall cannot be ignored, the prestress should be considered when analyzing the modal.

The first condition: Symmetry constraints are applied to the neutral surface of the furnace wall, the first ten natural frequencies are shown in Table 1, and the first vibration mode is shown in figure 7.

Table.1 the first ten natural frequencies of the furnace wall

order	1	2	3	4	5	6	7	8	9	10
frequency	2.316	2.549	2.583	2.584	2.628	2.695	2.738	2.755	2.807	2.811

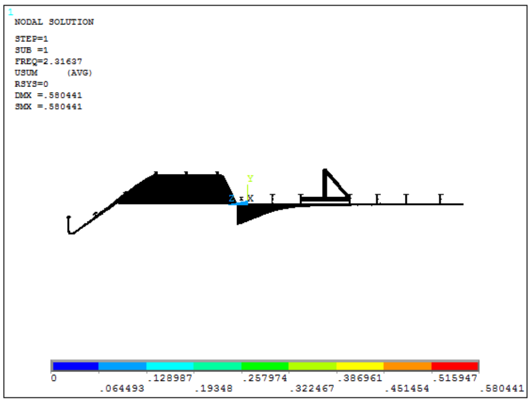

Fig.7 vibration model of the wall

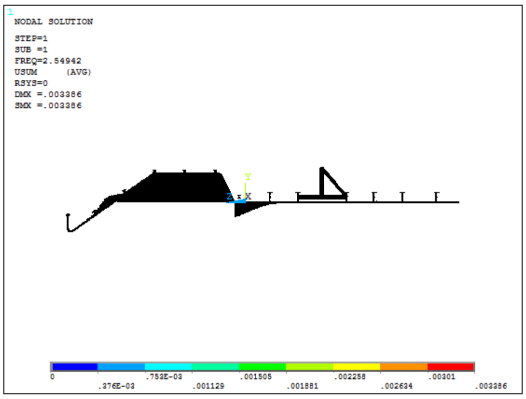

Fig.8 vibration model of the wall

The second condition: Anti symmetric constraints are applied to the neutral surface of the furnace wall, the first ten natural frequencies are shown in Table 2, and the first vibration mode is shown in figure 8.

Table.2 the first ten natural frequencies of the furnace wall

order	1	2	3	4	5	6	7	8	9	10
frequency	2.549	2.584	2.585	2.620	2.696	2.739	2.755	2.808	2.812	2.863

Through the modal analysis, it can be seen that the amplitude of vibration is mainly in the upper part of the furnace arch, which is perpendicular to the furnace wall. The vibration test data shows that negative pressure fluctuation excitation frequency and natural frequency are on the beat, which causing the resonance.

The way to solve this kind of problem is to strengthen the stiffness or design a device to stop shaking. The original dynamic characteristics of the furnace wall and the natural frequency are changed to avoid the excitation frequency through restraining the vibration amplitude.

5 Design and analysis of device

5.1 Design

To relieve the large shaking, the power plant has designed two kinds of devices which failed in solving the problem for not taking the dynamic and thermal expansion characteristics of furnace walls into account. Specific performance in: The horizontal rigid beam was bent or the joint of bearing beam and horizontal rigid beam was pulled off during use. In order to solve the above problems, this paper puts forward a kind of shake stopping device[6] to prevent boiler wall shaking which can increase the stiffness of furnace wall to resist normal deformation and avoid affecting the normal expansion of furnace wall and horizontal rigid beams, effectively controlling the low frequency sloshing . The specific device is shown in Figure 9, 10.

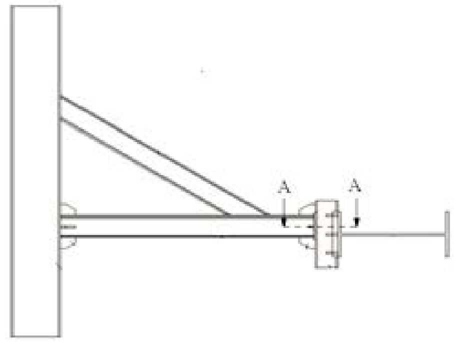

Fig.9 The front view

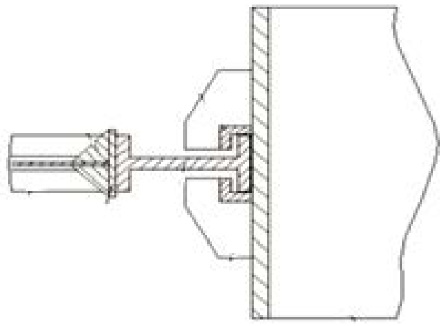

Fig.10 The view of A-A

5.2 Modal analysis

According to the vibration test and field investigation, four devices are installed on the horizontal rigid beam of each layer along the direction of the boiler height. A modal analysis is performed to investigate the possibility of resonance. Symmetry constraints are applied to the symmetrical neutral plane of the wall after installing the device and the first ten natural frequencies are obtained as shown in table 3. The results show that the natural frequency of the furnace wall is improved, which is in good agreement with the expected results.

Table.3 the first ten natural frequencies of the furnace wall

order	1	2	3	4	5	6	7	8	9	10
frequency	2.820	2.839	2.840	2.993	3.029	3.067	3.106	3.116	3.155	3.170

6 Conclusions

Based on the finite element ANSYS software, the three-dimensional finite element model of the boiler wall was established by using beam and shell elements to analyze the prestressed modal of the furnace wall. At the same time, it was found that the external excitation frequency and natural frequency are on the beat combined with vibration test data, causing the resonance that may lead to failure of related components of water wall tube, thus proper measures should be taken to suppress vibration.

Furthermore, considering the characteristics of the full suspension of the furnace wall and avoiding affecting the normal expansion of the wall, a slidable shake stopping device was designed to increase the lateral stiffness of the wall, increasing natural frequency and avoiding the resonance region effectively. The test, simulation and the design idea of the device provide a useful reference for solving the general problem of the shaking of the furnace wall, and have positive significance to prolong the lifetime of the boiler units in stable working conditions.

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