Research on Anti-cracking Technology of Water Wall in Supercritical W Flame Boiler

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Abstract. This paper introduces the order and operation performance of 600 MW supercritical W- flame boiler in China and Vietnam. The investigation and survey results about 600 mw supercritical W-flame boiler water wall cracking are indicated. The reason of water wall cracking is analyzed according to the boiler operation and the main reason is the furnace thermal deviation in horizontal direction. The paper indicated the performance and some measures to prevent the water wall cracking from design, installation and commissioning & operation in Vinh Tan 1 Power Company Limited. The fully mixing header is provided on the transitional section of the water wall, which is the most useful method to prevent the water wall cracking.

1. Introduction
Due to its special arched furnace and double U-shaped flame structure, W flame boiler makes the residence time of pulverized coal gas flow in the furnace increase, and the flue gas temperature at the root of the flame is significantly improved, which is very beneficial to the combustion of low volatile pulverized coal. Mainly used for the burning of anthracite. At present, the 600MW supercritical W flame boiler has some operational performance, but it has also exposed some problems in actual operation, especially the problem of water wall cracking and leakage. This paper combines the first phase BOT project of Vietnam Vinh Tan 1 Power Company Limited (abbreviation VTPC1), and has made a comprehensive technical analysis on this issue, and made a detailed summary analysis, and introduced the successful experience of the projects.

2. 600MW Supercritical W Flame Boiler in China and Vietnam
On July 4, 2009, DaTang Huayin Jinzhushan Thermal Power Generation Company Phase 2 3# furnace successfully passed the trial operation handover production, marking the world's first 600MW supercritical W-type boiler put into commercial operation. As of June 2018, China's 600MW grade supercritical W flame boiler has a total of 18 orders and operation results, and several major boiler manufacturers in China have had performance [1]. These 600MW supercritical W flame boilers have exposed some problems in actual operation, mainly related to leakage, cracking and deformation related to the boiler water wall.

Vietnam is rich in anthracite, and subcritical W flame boilers are widely used in this country. As of June 2018, there are 8 boilers being installed and put into operation. VTPC1 is the first supercritical W-fired boiler in Vietnam that uses Vietnamese anthracite. The unit capacity of the VTPC1 is
2x620MW, and the supercritical coal-fired generating unit produced in China is used. The Guangdong Electric Power Design Institute Co., Ltd. is responsible for the overall design and general contracting. The site is located in Vinh Tan commune, Tuy Phong, Binh Thuan, Vietnam. The No. 1 unit completed the 168-hour reliability test run on May 26, 2018, and was put into commercial operation on July 8, 2018. The No. 2 unit is plan to be put into commercial operation at the end of 2018.

3. Analysis of the causes of water wall cracking

According to the customer feedback in China, the problem of water wall cracking and leakage in the supercritical W flame boiler is mainly in the unit startup and the low load operation stage, because only part of the coal mill and burner are put into operation at this time. The heat load input in the furnace is not balanced, causing the temperature deviation between the water wall panels to be too large, resulting in limited expansion and cracking of the tube screen.

Based on the feedback from the power plants in China, the author conducted a statistical analysis of the causes of the water wall cracking and leakage problems, as shown in Fig. 1.

![Fig. 1 Statistics on the causes of water wall cracking](image)

According to the above figure, the large thermal deviation of the water wall is the most important reason, followed by over temperature of the water wall, installation defects, design and manufacturing defects, material defects, and improper operation. In essence, the excessive temperature and thermal deviation of the water wall is a problem of the same type, that is, the safety of the boiler water circulation.

3.1. Hydrodynamic calculation of threaded pipe with low mass flow rate

The hydrodynamic calculation of the threaded pipe with low mass flow rate was first carried out by SIEMENS. Subsequently, B&W of the United States conducted extensive and in-depth analysis of the test data of SIEMENS optimized internal threaded pipe and proposed improvement suggestions. At present, boiler manufactory in China have carried out a lot of research work on this technology, and proposed a series of safe operation measures for water wall. At present, the technology in China has become increasingly mature. Through the above engineering practice, the hydrodynamic calculation of the threaded pipe with low mass flow rate is safe and reliable, and there is no technical problem.

3.2. Over temperature and large thermal deviation of water wall

Now the boiler water wall is a membrane wall. In order to make the heat load of the water wall everywhere as balanced as possible, it is generally required when the boiler is ordered that the
temperature difference between the adjacent water wall shall not exceed 50 °C, the temperature difference between the wall of the header water wall shall not exceed 80 °C. According to the actual operation data of the above power plants, the temperature of the water wall can generally meet the above requirements under high load conditions. However, 
(1) during the start-up process, the temperature deviation of the water-cooled wall is large; 
(2) the local temperature of the water-cooled wall is over-temperature during the phase transition process; 
(3) when the load changes, the over-temperature phenomenon is likely to occur; 
(4) Under low load conditions, the water wall deviation is large, especially the position of the front wall.

3.3. Installation defects
The Fig. 2 indicates that the installation defect is also a factor that cannot be ignored in the water wall cracking leakage. According to the power plant feedback, there are mainly the following installation defects:
(1) The welder is not operating properly or the welding process requirements are not strictly enforced, resulting in poor weld quality.
(2) During the installation process, the rigid beam is not constructed as shown in the drawing, causing the expansion of the pipe screen in the hot state, which limits the expansion of the upper water wall in the left and right direction. The stress can only be absorbed by the deformation of the water wall panel itself, which causes the water wall tube to crack.

4. Project case introduction

4.1. Equipment and main operating indicators
The 620MW supercritical W boilers, steam turbines and generators of VTPC1 are all provided by Dongfang Electric Corporation (DEC). The design and check coal in this project are all anthracite in Vietnam. The boiler uses diesel oil as ignition and supporting combustion fuel. The relevant data are shown in Table. 1

| Item                                      | Unit     | Design coal | Check coal |
|-------------------------------------------|----------|-------------|------------|
| Total Moisture (air received basis), Mar  | %        | 7.08        | 10         |
| Volatile(dry ash-free basis), Vdaf        | %        | 10.8        | 8          |
| Ash (air received basis), Aar             | %        | 34.50       | 37.59      |
| Net calorific value (air received basis), Qnet.ar | kJ/kg    | 19132       | 17165      |
| Sulphur (air received basis), Sar         | %        | 0.55        | 0.75       |
| Hargrove grindability index, HGI          |          | 45          | 40         |
| Ash fusion point: deformation temperature DT | °C      | 1210        | 1160       |
| Soft temperature, ST                     | °C       | 1540        | 1530       |
| K2O                                       | %        | 4.10        | 4.12       |
| Na2O                                      | %        | 0.30        | 0.6        |

Table.1 Main analytical data of coal quality and ash
Table 2: Main technical data of boiler at BMCR condition

| Item                                | Unit | Design data | Running value |
|--------------------------------------|------|-------------|---------------|
| Maximum continuous rating            | t/h  | 1988.7      | 1987.0        |
| Super-heater outlet pressure         | MPa(a) | 25.41      | 24.21         |
| Super-heater outlet temperature      | ℃    | 571         | 565           |
| Reheat steam flow                    | t/h  | 1561.87     | /             |
| Re-heater inlet pressure             | MPa(a) | 5.23       | 4.64          |
| Re-heater outlet pressure            | MPa(a) | 5.04       | 4.71          |
| Re-heater inlet temperature          | ℃    | 331         | 324.1         |
| Re-heater outlet temperature         | ℃    | 569         | 561.8         |
| Unit output                          | MW   | 659.082     | 660.0         |

The boiler and its auxiliary machine, made by Dongfang Boiler Group Co., Ltd. is designed with the following parameters: supercritical parameters, variable pressure once-through, W-type flame, dry bottom, single furnace, single reheat, balanced ventilation, outdoor installed, all steel framework, fully suspended n-type structure, synchronously installed SCR flue gas de-nitration system. The boiler equipment is ignited by a conventional large oil gun, and the oil is micro-explosively atomized by compressed air. The milling system adopts double ended ball mill and positive pressure cold primary fan direct-blowing pulverizing system. Each furnace uses 6 sets of MGS series double ended ball mills, no spare equipment, 12 sets of electronic weighing belt type coal feeders, and 2 sets of rotor blades adjustable axial-flow primary fans. The sealing wind of the coal mill is from the cold primary air duct. Two centrifugal sealing fans are installed, one for operation and one for standby. The main design and operating parameters of the boiler BMCR operating conditions are shown in Table 2.

4.2 Water wall temperature operation

The No.1 boiler of VTPC1 began to ignite on January 28, 2018, and completed the 168-hour reliability operation test on May 26, 2018. During the period, the water wall did not overheat and the maximum wall temperature difference between adjacent tubes was $<20^\circ C$, the maximum difference of the wall temperature measurement point of the water wall is $<50^\circ C$.

4.3 High load

According to the previous operating experience of the same type of unit, the front wall water wall is most prone to cracking under long-term high-load operation. Since the commercial operation of this project, due to the large demand for electricity in Vietnam, the unit has been in full load or even overload operation. From the operation data display (as shown in Fig. 2), the total temperature of 264 temperature measurement points on the front wall did not appear to be over-temperature, and the temperature distribution was uniform, the deviation was small, and no water-cooled wall leakage occurred.
Fig. 2 Temperature values of the front water wall at BMCR conditions

5. Measures to prevent cracking of water wall
The water wall cracking of W flame boiler is an important factor affecting the safe and reliable operation of the unit. It is related to design, installation, operation and maintenance, etc. It also needs the prevention measures from the above aspects. The following is a description of the various measures taken in VTPC1 to prevent the cracking of water walls [3].

5.1. Main measures in the design selection stage

(1) Setting the water-cooled wall intermediate full mixing header
The boiler manufacturer of VTPC1 cancels the original single mixing box around the furnace, increases the distance between the rigid beams, adds the lower water wall outlet header, the upper water wall inlet header, and sets a large set on each side of the boiler. The box ensures that the lower water wall outlet working medium can be fully mixed here and then distributed to the upper water wall. According to the calculation and the actual measurement comparison, the deviation of the upper water wall can be reduced by about 10~20 °C.

(2) Optimize the length from header centerline to the end of the flat screen
In order to avoid the cracking of the header pipe socket on the front wall water wall, boiler manufacture has optimized the connection length of the upper water wall pipe panel to the header. The length of the original structure header box center line to the pipe screen flat steel end will increase. The pipe joint is reduced from the maximum stress of 1388 MPa to 116 MPa of the original structure, which is equivalent to the maximum stress value of 108 MPa using the curved pipe, so as to ensure that the front wall water-cooled wall header pipe joint does not generate fatigue cracks. The above improvement measures have been implemented in the other supercritical W flame furnaces [4].

(3) Appropriately increase the number of measuring points for water wall temperature monitoring system
In order to better monitor and judge the safe operation of the furnace wall, the project optimizes and increases the temperature measurement point of the water wall, combined with the same type of boiler experience, the actual site is 474 points, including 164 points on the upper front wall, upper side The wall is 74 points, the lower front wall is 100 points, the lower rear wall is 100 points, and the lower side wall is 72 points.

(4) Optimizing boiler refractory belt layout
The 6A1 anthracite coal of northern Vietnam was used in VTPC1. The coal has the characteristics of being difficult to catch fire and hard to burn. In order to ensure combustion stability and combustion efficiency, it is necessary to arrange a suitable refractory belt in the burner area, but also to avoid the
boiler being easy to appear. Severe ash deposition and coking, resulting in poor heat transfer, over-temperature and even bursting of water-cooled walls, combined with the high content of Na and K in the coal, the hot surface is easy to foul. The design optimization of the boiler refractory belt and water cooling wall arrangement are taken to improve boiler hydrodynamic characteristics.

The design of the supercritical W flame boiler is based on the optimization of the natural circulation characteristics of the internally threaded pipe with a sub-critical boiler at a low mass flow rate (less than 1200 kg/m²·s), and the mass flow rate is low (the water volume of the water wall is about 25% of the critical furnace water wall is 30% smaller than the conventional supercritical furnace), and the water-cooled wall tube has a small flow area. A carefully design and calculation about the hydrodynamics of the low-quality flow-end internal threaded pipe was executed. The boiler manufactory optimize the arrangement of the water-cooled wall, and prevent the water-cooled wall from over-temperature and large thermal deviation, especially in low-load and variable-duty conditions.

(5) Optimizing the powder feeding pipe arrangement
Supercritical W flame boiler can only be used with the vertical water wall due to the width of the furnace and its burners are arranged at one elevation. According to the analysis of the water wall cracking of other similar types of power plants, the large thermal deviation of the water wall is the main reasons for wall cracking. Reducing the input heat deviation of the burner is a core task, so it is necessary to ensure uniform for each pulverized coal piping and stable combustion. A dynamic separator of mill was used. It is required that the fineness of pulverized coal is R90≤6%, the uniformity index of pulverized coal is n≥1.1; the deviation of air volume at the outlet of each side of the coal mill should not exceed ±5 %, and the deviation of pulverized coal concentration with hot primary air should not exceed ±5 %; The temperature deviation of the separator for one mill does not exceed 10 °C, and the pulverized coal concentration deviation does not exceed ±10%.

(6) Reasonable selection of materials
In order to prevent water wall blasting, the super-heater and re-heater should be calculated for thermal deviation, the deviation coefficient should be selected reasonably, and the influence of smoke temperature deviation should be fully considered. When selecting the pipe, there is sufficient safety margin based on the wall temperature check. The material strength calculation allows the difference between the temperature and the highest calculated wall temperature to be greater than 15 °C.

5.2. Measures during the construction phase
(1) Boiler expansion system quality control
One of the major reasons for the cracking of the water wall is that the boiler has not been constructed according to the drawings, and the sliding point is erroneously welded, causing the expansion of the boiler to fail to expand according to the design requirements. During the installation process, the construction organization shall strictly supervise the construction according to the drawings. In order to ensure the flatness of the water-cooled wall panel to prevent deformation, the construction organization is required to assemble on the ground as much as possible. The inspection of the rigid beam gap and the angle inspection of the corner joint are strengthened to ensure the expansion of the water wall Design and focus on the welding and release of fixed points, expansion points. Hire a professional company to the site to conduct 100% RT inspection of the weld, and strengthen the quality inspection of the weld.

(2) Adjusting the pre-signal of the feed water flow when the load changes
When the boiler is raised and lowered, it is particularly prone to cause the water-coal ratio to be out of adjustment, thereby causing the temperature of the heated surface including the water-cooled wall to rise. Therefore, before the boiler is loaded, the main steam temperature can be appropriately reduced, and the water supply amount and the fuel amount can be adjusted in time according to the steam temperature and the wall temperature change of the water wall. The power plant can adjust the feed water flow pre-signal when the load changes according to the operating experience, which can alleviate the problem that the fuel quantity adjustment is not timely enough.
(3) Coal mill operation mode

In the process of boiler starting and load increasing, the heat load input in the front and rear walls and the width direction of the furnace shall be uniform as far as possible. Each mill should be controlled to the lowest capacity air volume, and then slowly and smoothly increase the output of the coal mill. In normal operation, it should be noted that the output of each coal mill should be uniform, the output of the two coal feeders of the same coal mill should be basically the same, and the two winds should be basically the same on both sides. The operation of the large-capacity wind operation should be controlled. During the adjustment process, observe the temperature change of the superheater tube wall and adjust the capacity wind opening in time.

(4) Operation mode of ignition phase

In the initial stage of ignition, the super-heater is mainly protected by limiting the furnace outlet flue gas temperature and increasing the steam flow. In the low load stage, the steam temperature should be controlled by de-superheating water or deferred baffle, and the load should be increased as much as possible to increase the steam flow. The milling system can only be started if the main parameters such as the main and reheat steam temperatures are appropriate, stable and the temperature of the de-superheating water is certain. Before the start of the milling system, the preparation should be sufficient and the start-up plan should be considered.

(5) Water wall temperature monitoring

Closely monitor the temperature of each section of the pipe wall and find that the over-temperature condition is treated in time. The wall temperature control value of each section is strictly in accordance with the boiler wall temperature calculation result. The alarm is set on the DCS, and the temperature of the super-heater and re-heater outlet wall temperature shall be controlled. The wall temperature deviation between any adjacent two tubes does not exceed 50°C, and the temperature deviation between any two non-adjacent tubes does not exceed 80°C.

6. Conclusion

600MW grade supercritical W flame boilers are widely used in China, but there are widespread problems of over-temperature and cracking of water walls. As the first 600MW grade supercritical unit in Vietnam, VTPC1 has a series of improvements and the unit has been successfully put into operation.

The reason for the over-temperature and cracking of the water wall of the 600MW supercritical W flame boiler is mainly due to the over-temperature and thermal deviation of the water-cooled wall. In addition, the design and manufacturing defects, the installation defects, and improper operation are also important reasons.

The fundamental method for solving the water wall cracking of the 600MW supercritical W flame boiler is to reduce the thermal load deviation of the water wall from the design, and to set the water wall completely mixed header around the furnace to reduce the deviation of the upper water wall by about 10~20°C.

In order to avoid the crack phenomenon of the header pipe on the front water wall, the stress can be eliminated by adjusting the length of the free expansion section of the header pipe, and the stress of pipe joint is reduced from 1388 MPa to 116 MPa.

The boiler installation quality and the rationalization measures during the commissioning and running are significant to prevent the water wall from cracking.

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