Analysis on the cause of crack in connection pipeline of subcritical boiler reheater

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Abstract: Several coal-fired thermal power boilers with the same sub-critical parameters in Mengxi area of Inner Mongolia have successively suffered from cracking and leakage failure events of reheater connecting pipes, most of which occur at chamfered back tool grooves on the inner wall grooves of pipe welding joints. In order to find out the cause of cracking, typical failure samples were intercepted for macro-morphology, microscopy, SEM, chemical composition, mechanical properties, wall thickness measurement analysis and design and operation data investigation of several boiler equipment. The results show that comprehensive factors such as deviation of burning coal type from design of boiler, automatic dispatching of AGC load in power grid, low nitrogen combustion modification and so on cause changes in boiler combustion conditions and operation, which results in excessive high input level of reheater cooling water, resulting in long-term alternating thermal stress and non-periodic vibration of straight pipe and elbow arranged after fine-tuning of refrigerant flow direction in reheater. Finally, thermal fatigue cracks are induced to initiate and propagate through the stress concentration area of the chamfered knife groove of the inner wall of pipe welded joints.

1. Introduction

1.1. Failure condition

From 2014 to 2019, several coal-fired thermal power boilers with sub-critical parameters of the same type have successively experienced cracking and leakage failure events of reheater connecting pipes in Mengxi area, Inner Mongolia. Details are shown in Table 1. This type of boiler in Mengxi has been put into operation for 10 boilers from 2006 to 2007 and 2 boilers from 2009 to 2010. Medium speed coal mill positive pressure cooling primary air direct-blown pulverizing system is used in the boiler.
Table 1 Statistics of failure of reheater connecting pipes

| Boiler number | Boiler type          | Date of commissioning | First expiration date | Failure location                                      |
|---------------|----------------------|------------------------|-----------------------|------------------------------------------------------|
| JS#2          | DG1065/18.2-II6      | January 2010           | September 2019        | Groove undercut of butt joint of right straight pipe of boiler |
| JQ1#1         | DG1065/18.2-II6      | August 2006            | August 2017           | Groove undercut of butt joint of left elbow of boiler   |
| JQ#2          | DG1065/18.2-II6      | November 2006          | June 2014             | Groove undercut of butt joint of left elbow of boiler   |
| BY#1          | DG1065/18.2-II6      | October 2007           | July 2019             | Groove undercut of butt joint of right straight pipe of boiler |
| XF#2          | DG1065/18.2-II6      | August 2017            | December 2016         | Groove undercut of butt joint of left straight pipe of boiler |
| LH#1          | DG1065/18.2-II6      | June 2006              | September 2015        | Groove undercut of butt joint of left elbow of boiler   |
| LH#2          | DG1065/18.2-II6      | April 2007             | May 2019              | Groove undercut of butt joint of left straight pipe of boiler |

1.2. Reheater Arrangement

The reheater steam system is divided into three stages: wall type reheater, medium temperature reheater and high temperature reheater. After the high temperature superheated steam works in the steam turbine, it is guided into the inlet header of the wall type reheater by the cold section pipe of the reheater steam, and an accident water spray thermostat is set before the header inlet. The wall reheater is arranged staggered with the water-cooled wall. After absorbing the radiant heat of combustion in the furnace, it enters the outlet header of the wall reheater vertically upwards (457.2×25mm, 20G). The reheated steam enters the inlet header of the medium temperature reheater (457.2×25mm, 20G) through the connecting pipes (609.6×22.2mm, 20G) and from the left and right sides of the boiler. A fine-tuned water jet thermostat (609.6×30mm, 20G) is arranged in the connecting pipes on the left and right sides respectively. Reheated steam enters the high-temperature reheater through the medium-temperature reheater. There is no header between the medium-temperature reheater and the high-temperature reheater to reduce the resistance of the reheater system.

1.3. Temperature regulation mode of reheater

The boiler adopts the tangential combustion method with four corners. The centerline of the four corners burner is tangential to two hypothetical circles at the center of the furnace. The diameters of the two hypothetical tangential circles are 548mm and 1032mm respectively. There are 13 layers of nozzles in each corner of the burner. The swing range of the upper group of nozzles and the lower group of nozzles are <30 degrees and <15 degrees respectively. The swing of the nozzle is driven by a pneumatic actuator. DG 1065/18.2-II6 boiler regulates and controls the reheat steam temperature in two ways, one is the swing control of the flue gas side burner and the other is the spray control of the steam temperature of the steam side thermostat. On the flue gas side, the height of the furnace flame center is changed by swinging the angle of burner nozzle, so as to change the flue gas temperature at the outlet of the furnace, change the heat absorption ratio of superheater and reheater, and realize the purpose of reheating steam temperature regulation. However, compared with the change of boiler load, the way of regulating reheating steam temperature on the flue gas side has certain time lag [1]. On the steam side, a fine-tuned water spray thermostat is used to spray low-temperature and high-pressure water into the mixing sleeve through spray nozzle atomization and mix the superheated steam in the pipe sufficiently to regulate and control the temperature of the reheated steam. Compared with the flue gas side temperature control mode, the steam side temperature control mode by means of reducing temperature water has the advantages of sensitive reaction, high adjustment accuracy and easy to realize automatic control [2-5].
2. Test Analysis
In order to find out the common causes of frequent failures of connecting pipes of several DG1065/18.2-II6 type boiler reheatrs, the cracks of connecting pipes of left Reheater of LH#2 boiler are selected for test and analysis. The material specifications are 609.6×22.2mm and 20G. According to the direction of media flow, failure occurs mostly at the chamfered turning area of the butt joint between the straight pipe and the reducer header after the reheater fine-tuning reducer or the butt joint between the elbow and the straight pipe.

2.1. Observation and analysis of macroscopic morphology
The macro-morphological observation shows that the cracking of the inner wall of the pipe is located at the variable section of chamfer turning area of the straight pipe butt joint, parallel to the circumferential cracking of the weld, about 20mm away from the axial direction of the weld and about 400mm in length, as shown in Figure 1. There are many circumferential turning tool marks on the inner wall of the pipe. The surface is rough. The chamfered thickness of the joint groove is 4mm. The chamfered back tool groove cracks annually and the cracks are straight as shown in Figure 2. The reheater fine-tuning thermostat header is welded to the connecting pipe. The outer diameter of the two components is the same and the wall thickness is 3.9mm different. Therefore, there is a thickness difference between the welding grooves. According to DL/T 869, two pipe fittings with unequal wall thicknesses shall be turned at the groove before welding to ensure that the inner wall is flush during assembly welding. Because the turning process does not meet the requirements of specifications, the transition of turning on pipe inner wall groove is steep, and the smooth transition process is not adopted as required by specifications, resulting in a stress concentration area.

Figure 1 Macro-morphology of cracked area

Figure 2 Macro-morphology of cracked part

2.2. Observation and analysis of fracture morphology
From the observation of the fracture section, it can be seen that the crack originates in the inner wall of the pipe and extends towards the outer wall of the pipe. The initial crack area and the crack propagation area can be clearly observed as shown in Figure 3. SEM scans revealed fatigue striations near the outer wall of the pipe as shown in Figure 4.
2.3. Microstructure Observation and Analysis

The cracks in the reheater connecting pipes were examined by microscopy as shown in Figure 5. The metallographic structure at the crack is equiaxed ferrite + pearlite with uniform distribution. No obvious distortion and deformation of grains occur. The degree of spheroidization is grade 2, which belongs to inclined spheroidization. The structure is normal and no abnormal structure and defects are observed.

2.4. Other detection and Analysis

The chemical composition test, mechanical property test (yield strength, tensile strength) and wall thickness measurement of the cracked part of the reheater connecting pipe are carried out. The results show that the chemical composition and mechanical property of the pipe conform to the requirements of seamless steel pipe for high-pressure boiler. The minimum wall thickness measurement is 21.46 mm, which meets the design strength requirements.

3. Equipment operation analysis

3.1. Thermal expansion analysis

Variable spring hanger “TD120D18” is installed in the outlet header of the wall re heater, variable spring hanger “TD60D18” is installed in the fine-tuning thermostat, and variable spring hanger “TD30D15” is installed in the inlet header of the medium-temperature re heater. The above variable spring hangers are in normal condition without damage or seizure. According to the expansion design, the displacements of the outlet header of the wall type re heater and the inlet header of the medium
temperature reheater are shown in Table 2. The reheater connection piping is arranged as shown in Figure 6.

| Items                                      | Downward displacement | Displacement to furnace front | Displacement to the back of furnace |
|--------------------------------------------|-----------------------|-------------------------------|-----------------------------------|
| Outlet header of wall reheater             | 2.7mm                 | 31.7mm                        | --                                |
| Inlet header of medium temperature reheater| 23.4mm                | --                            | 23.9mm                            |

Figure 6 Reheater connection pipe layout

The length of connecting pipe between the outlet header of the wall type reheater and the inlet header of the medium temperature reheater is 1240.74mm, the length of the fine-tuned reducer header is 4849.66mm, the height difference between the connecting pipe and the outlet header of the wall type reheater is 2800.00mm, and the height difference between the inlet header of the medium temperature reheater is 2300.00mm. Under VWO operating conditions, the working fluid temperature of the connecting pipeline is 398℃. The calculation shows that the total expansion of the connecting pipeline is 59.00mm (the linear expansion of 20G at 400℃ is 13.8×10⁻⁶/℃). By calculation, the designed expansion value can fully satisfy the expansion requirement of connecting pipes, and the connecting pipes are large-bore thin-walled pipes with inverted U shape and good flexibility. Therefore, the pipe expands smoothly without additional stress due to blocked expansion.

3.2. Structure Analysis of Thermostats

The reheater fine-tuned thermostat consists of a single row of perforated water jet nozzles and a mixing sleeve. The flow direction of the cooled water is the same as that of the reheated steam. One end of the mixing sleeve is fixed by a positioning screw arranged circumferentially and the other end is fixed by a cylindrical pin to allow full thermal expansion. The structure of the thermostat is shown in Figure 7.

According to the boiler design, the fine-tuned temperature-reducing water of the reheater is taken from the middle tap of the feed water pump and put into the mixing sleeve after the pressure-reducing valve is depressurized. According to the thermal calculation of the boiler, the reheater steam flow under VWO condition is 874.90t/h, the reheater system/outlet pressure is 4.02/3.83MPa, the outlet temperature of the wall reheater working medium is 398.00℃, the inlet temperature of the medium temperature reheater working medium is 393.00℃, the water injection quantity of the reducer is 4.73t/h, the water injection temperature of the reducer is 184.60℃ (with high operation); and the reheater steam flow under TRL condition is 844.77t/h, the system/outlet pressure of the reheater is 3.88/3.70MPa, the outlet temperature of the wall type reheater is 397.00℃, the inlet temperature of the medium temperature reheater is 394.00℃, the spray volume of the reducer is 2.51t/h and the spray temperature of the reducer is 183.00℃ (with high heating operation). The reheater fine-tuned thermostat has a maximum total water spray of 18.40 t/h. It can be seen from this that the amount of cooling water input in the reheater fine-tuning thermostat for boiler design is small and the single row
The porous nozzle used can meet the requirement of fully atomized cooling water. In response to AGC dispatching and peak shaving requirements of the power grid, boiler loads change rapidly and frequently, while the response of the reheater system flue gas temperature regulation lags behind. In order to avoid overheating and overheating of reheater tubes, excessive cooling water is required to regulate the reheater steam temperature. Cooling water with temperature difference of 214°C is mixed with superheated steam at high temperature to produce vibration excitation force and thermal stress. Long-term operation easily causes fatigue cracking and fracture of porous jet water pipe under vibration and alternating thermal stress, and also causes defects such as scouring of jet water holes and enlarging of bore diameter due to excessive cooling water. The nozzle of the fine-tuned thermostat for LH#2 reheater is damaged by the scouring of cooling water, the nozzle holes are connected in series, and the atomization ability decreases dramatically, as shown in Figure 8. LH#2 left reheater fine-tuning thermostat mixing sleeve is broken as shown in Figure 9.

3.3. Analysis of cooling water quantity

Based on the analysis of boiler operation data, it is known that the input of fine-tuned cooling water for reheater is 48.9t/h, 2.6 times of the designed maximum water injection, one month before the cracking and leaking of the connecting pipe of the left Reheater of LH# boiler. Reasons for excessive input of cooling water: (1) The design of fine-tuned cooling water for reheater is mainly put into use during start-up and shutdown of the unit, and the steam temperature control is mainly carried out by swinging burner during stable operation, while the fine-tuned thermostat is used as an auxiliary means for steam temperature regulation on steam side. In recent years, the relationship between coal supply and demand in the power market and the annual average effective utilization hours of generators have decreased year by year, which makes the burning coal types of boilers deviate from the design, the quality of coal and its heat change greatly, and the steam temperature control is forced to adopt the method of increasing the input of cooling water. (2) The unit adopts automatic generation control.
(AGC) system of power grid, and the unit load is regulated by power grid dispatching center. According to the requirements of specifications, the load adjustment range of AGC unit in Mengxi power grid is 50% - 100% of the load. For the drum boiler of direct-blown pulverizing system, the load change rate of the thermal power unit is not less than 1.5% of the rated power (DG 1065t boiler auxiliary unit rated power is 300 MW). The dispatching of AGC system requires fast response of boiler load. In order to avoid over-temperature and over-heat damage of reheater tube as far as possible, the dropping frequency and spraying quantity of reduced temperature water are greatly increased. (3) The burning condition of the boiler changes. Low nitrogen combustion modification changes boiler combustion conditions, resulting in changes in outlet temperature of flue gas temperature and the ratio of heat absorption of superheater and reheater [6-9].

3.4. Common Issue Analysis
Seven boilers with cracks and failures of reheater connecting pipes have been fully investigated and tested with the following common characteristics: (1) straight pipe or elbow cracks occur in chamfered back slots with variable cross-section at weld joint grooves on inner wall of pipes and are characterized by thermal fatigue cracks; (2) deviations from design of burning coal in power plants, changes in coal quality and heat generation; (3) power grid is used for generator units. Automatic generation control (AGC) system, which regulates unit load by power grid dispatching center; (4) large amount of cooling water input of each power plant. If the total amount of fine-tuned cooling water input to the left and right side of the JQ #1 boiler reheater reaches 44.50t/h, the total amount of fine-tuned cooling water input to the left and right side of the JQ #2 boiler reaches 48.20t/h, the amount of fine-tuned cooling water input to the left and right side of the XF #2 boiler reaches 39.90t/h, and the maximum amount of fine-tuned cooling water input to the left and right side of the BY #1 boiler reaches 32.70t/h, the fine-tuned heating water input to the far-beyond the reheater ensures that there is fine-tuned cooling water input to the right side of the XF #2 boiler. Spraying capacity of fully atomized and uniformly mixed cooling water in service stroke.

4. Conclusion
In conclusion, during the operation of 7 DG1065/18.2-II 6 boilers, the steam temperature needs to be regulated by fine-tuning thermostat of reheater, which is frequently put in and over-invested for a long time. As a result, sufficient atomization and uniform mixing of the cooling water within the length of the original mixing sleeve can not be realized, thus the straight pipe and elbow arranged after the flow of the working fluid of the thermostat can withstand the low temperature workers. Thermal stress is caused by mass impact. At the same time, insufficiently atomized water droplet working fluid impinges on the inner wall of the connecting pipe, causing non-periodic vibration of the pipe. With the long-term operation of the boiler, the non-periodic alternating thermal stress and vibration acting on the pipeline induce the initiation of thermal fatigue cracks in the stress concentration area of chamfered back groove of welded joint and the propagation and penetration, which is the direct cause of the failure of the reheater connecting pipeline.

The comprehensive factors such as deviation of burning coal type from design of boiler, automatic dispatching of AGC load in power grid, and retrofit of low nitrogen combustion result in changes of burning and operating conditions of the boiler, which makes the amount of heat-reducing water in the reheater at an excessively high input level, and is the main reason for cracking and failure of connecting pipes of the boiler reheater.

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