Analysis of nondestructive testing method for transverse crack of water wall of Supercritical Boiler

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Abstract. According to the mechanism and characteristics of transverse crack of water wall steel tube, the feasibility, advantages and disadvantages of non-destructive testing methods such as visual testing, magnetic particle testing, ultrasonic testing, eddy current testing, penetrant testing and radiographic testing for transverse crack detection are described. The results show that the array eddy current and far-field eddy current have the advantages of small amount of work, high sensitivity, convenience and high efficiency when they are used to detect the transverse crack of the water-cooled wall steel pipe in service.

1. Introduction
In recent years, domestic super (super) critical units develop rapidly, Inner Mongolia as an energy base, a number of super (super) critical units (including efficient ultra-supercritical units) have been put into operation. With the accumulation of operation time of units, and the influence of fast change of boiler load and low nitrogen combustion mode accompanied by coal deviation design, unit peak regulation, the common problem of early failure of “transverse crack” of boiler water wall of supercritical units is also exposed in mengxi area.

The membrane water-cooling wall is formed by the welding of steel pipe and flat steel, which is not only the rigid supporting internal wall of boiler furnace, but also the main heating surface to absorb radiant heat from combustion in the furnace, and the heat absorption accounts for 40 ~ 50% of the total heat.

2. Causes of transverse crack
The specification of water wall tube of domestic 600MW and 1000MW supercritical unit boiler is generally Ф28.6~Ф35mm, and the material is generally 15CrMoG, 12Cr1MoVG, T12 and other low alloy heat-resistant steel.

There are common problems in the early stage of transverse crack of water wall tube of Supercritical Unit Boiler in China, which have the following characteristics: (1) transverse crack often occurs in the early stage of unit operation, generally no more than two a repair cycles, and even some units have transverse crack failure in 4000h operation. (2) The water wall tubes with transverse cracks are located in the high heat load area of the furnace, mostly between the upper burner and the middle header of the water wall. (3) The transverse cracks are mostly produced in the outer wall of the vertical section of the water wall pipe to the fire side, and the direction of the cracks is vertical to the pipe axis,
which is in a dense and parallel distribution state. The crack begins to expand inward from the outer wall, the crack tip is blunt and does not bifurcate, and the inside is full of corrosion and oxide. There is no oxide skin or crack on the outer wall of the back fire side. Bainite lines with obvious fatigue characteristics can be seen on the fracture surface of the pipe, which belongs to thermal fatigue crack.

The transverse cracks in the water cooling wall of supercritical unit boiler are examined macroscopically, analyzed by chemical composition, tested by mechanical properties, tested by metallography and analyzed by energy spectrum. The main reasons are as follows[1]-[6]:

(1) thermal fatigue. The membrane water-cooled wall is composed of welded steel pipe and flat steel. The axial rigidity of the water-cooled wall is large and the expansion degree of freedom is large, while the transverse rigidity is small and the expansion is constrained by the adjacent steel pipe and flat steel. When the temperature of the outer wall of the water-cooled tube changes greatly, alternating thermal stress will be generated along the axial direction of the tube. When the boiler load changes, such as boiler start and stop and peak regulation conditions can cause the wall temperature of water-cooled wall tube to fluctuate greatly. When the boiler is running stably, the wall temperature of the water-cooled wall tube can fluctuate greatly due to the fact that the hydrodynamic distribution of the water-cooled wall fails to meet the design requirements or there is a foreign body blockage in the collecting box.

(2) sulfur corrosion. When the load changes or the temperature gradient is large, cracks appear in the oxide skin on the fire surface of the pipe, and corrosive substances infiltrate into the oxide skin cracks. It is confirmed by energy spectrum analysis that the corrosive substances in the crack are mainly sulfide. Micro - dot corrosion pits are easy to be crack sources.

Under the action of axial alternating stress and high temperature sulfide corrosion, the pipe produces transverse crack, which expands rapidly under the mutual promotion of stress and corrosion, and finally leads to leakage failure.

To sum up, such transverse cracks usually occur not as a single pipe or single crack, but in a certain area of the water-cooled wall with poor hydrodynamic circulation, or in a region with high thermal load after the change of combustion characteristics caused by the change of coal type. The early transverse crack in the water-cooled wall has led to frequent nonstop tube burst adverse events in several units. Therefore, it is necessary to choose an effective and fast nondestructive testing method.

3. Transverse crack detection method
A certain power plant model for SG-2141/25.5 of a reheat, balancing the structure of ventilation, the whole suspension π type pulverized coal fired boiler, water wall tube, the transverse crack on a number of occasions for the first time found that the water wall transverse crack failure when the unit running about 19000h. Water wall material of 12Cr1MoVG, specifications for Ф35×6.2 mm. The macroscopic morphology of transverse crack in water-cooled wall tube is shown in figure 1. The microstructure of the crack is shown in figure 2. There are several circumferential cracks parallel to each other in the outer wall of the fire-side pipe of the steel tube, each of which has a different depth (crack depth of 0.1mm ~ 6.2mm), showing the characteristic of extending from the outer wall of the steel tube to the inner wall.
In view of the defects of the boiler water wall tube and its transverse crack, this paper discusses the applicable nondestructive testing method.

3.1 Visual inspection
Visual inspection (VT) can be divided into direct visual inspection, indirect visual inspection and transmittance visual inspection. In direct visual inspection, the distance between the eyes and the surface of the workpiece under inspection shall not exceed 600mm, and the Angle between the eyes and the surface of the workpiece under inspection shall not be less than 30 degrees, and the illumination of the surface of the workpiece under inspection shall be at least 500Lx. Indirect visual detection can be carried out by video system or uav remote video system in real time. Either way, it is necessary to remove the ash and slag attached to the inspected area, or the cracks will be covered easily.

Advantages of visual inspection: under suitable environmental conditions, the efficiency of visual inspection is higher than other non-destructive inspection methods, and the detection rate of surface open cracks is higher. Visual detection can omit more instrument calibration steps and operating procedures, the detection speed can reach magnetic particle detection (MT) speed of more than three times, penetration detection (PT) of more than eight times. Under appropriate conditions, the human
eye resolution can be up to 0.2mm, that is, the width of the article ≥0.2mm can be detected, but if the staff use magnifying glass or microscope, the detection sensitivity is higher[7]. The erosion thinning defect was found by visual inspection of the water-cooled wall, as shown in figure 3.

Direct visual detection is suitable for rapid screening of transverse cracks with the opening width of water-cooled wall tube greater than or equal to 0.2mm in the area of high heat load when the furnace is equipped with lifting platform. The uav video inspection system can be used to check the structure parts in the furnace that cannot be reached by personnel, or it is suitable for the situation of high temperature in the furnace during the boiler emergency repair.

3.2 Magnetic particle detection

Magnetic particle detection is applicable to the detection of small surface and near-surface sizes of ferromagnetic materials, extremely narrow gap (such as detection of crack length of 0.1mm, width of micron level), and visually difficult to detect crack defects.

The water-cooled wall tube is made of low-alloy heat-resistant steel, and the crack direction is perpendicular to the axis. Therefore, non-fluorescent magnetic particle detection can effectively detect the transverse crack, and the detection speed is faster. The strong brightness in the furnace is needed to ensure the safety of workers, so fluorescent magnetic powder detection is not applicable.

Due to the limitation of skin effect, the effective detection depth of ac yoke method is lower than that of dc yoke method. The transverse cracks of the water-cooled wall tube are the first crack on the outer wall of the fire side, and several of them are distributed in parallel, but there are few internal cracks buried under the surface of the outer wall. Considering the safety and operation convenience of the furnace detector, it is recommended to use the dc magnetic yoke method for detection, which can meet the requirements of transverse crack detection sensitivity.

The dc magnetic yoke method is used to detect the defects of pressure equipment, as shown in figure 4. The flaw property can be determined as a crack by the figure, and the shape, location, length and other information of the crack can be visually displayed.
Advantages of magnetic particle detection: high detection sensitivity, the minimum defect width that can be detected can be up to 0.1 m, can find the depth of microcracks only more than 10 microns, can adapt to various geometric shapes of the workpiece, can adapt to the field operation in various occasions, detection speed is faster, more convenient operation.

3.3 Ultrasonic testing

At present, the mature technologies based on ultrasonic principle include type A pulse ultrasonic testing (UT), diffraction time difference ultrasonic testing (TOFD) and phased array ultrasonic testing (PA).

In UT detection, the wall thickness of the small diameter tube is thin, the near-field area of sound field is used, and the wave type conversion is frequent, which leads to the difficulty in quantification and signal recognition. The small diameter tube has large curvature, distortion of sound field and low detection rate of transverse crack.

TOFD testing is applicable to workpiece thickness of 12mm or more, not applicable to thin-walled small diameter tube substrate and welding seam testing.

With its unique multi-angle scanning characteristics, focusing characteristics and imaging methods, PA detection can effectively detect various surface defects and volumetric defects in the workpiece. Ultrasonic phased array detection technology has the following characteristics: the Angle of the sound beam, the position of the focal length and the size of the focus can be dynamically adjusted within a certain range. At the same time, the sound beam of the transducer of the phased array can be rapidly shifted by software control. With the above advantages, ultrasonic phased array can realize the detection of many complex structures. The sound velocity coverage of phased array ultrasonic technology is shown in figure 5. It can be seen from the figure that the transducer does not move at a fixed position, and the sound beam coverage of the whole section can be realized by adjusting the delay law of the emission excitation of the chip in the transducer.
the crack defect, as shown in FIG.6. The focal spot in the figure is a transverse crack defect. The crack length is 9mm and the depth is 1.9mm.

FIG.6 Image of ultrasonic phased array detection

PA has a high detection rate when detecting such area-type defects as crack and unfused, and a high detection rate when detecting such defects by radiography. However, the acquisition cost of instruments and equipment for PA testing is high, and the transducers used are easy to wear out. For example, large areas of water-cooled wall tubes are screened, and the cost of testing is higher than that of magnetic powder testing, permeability testing, eddy current testing and X-ray testing.

3.4 Eddy current testing

3.4.1 Array vortex: Compared with single-channel eddy current detection, which has a small sweep coverage area and low sensitivity, multi-channel array eddy current detection has a large sweep coverage area and high sensitivity, which can detect the workpiece with complex geometric shapes, and its detection reliability and detection rate are greatly improved.

Literature [8] used array eddy current detection technology to detect the transverse crack caused by thermal fatigue of water cooling wall of a power plant in Inner Mongolia. The sensitivity of eddy current detection under two surface conditions is firstly demonstrated in the literature. Artificial defect grooves were etched on the water-cooled wall sample tubes that had been mechanically polished and the water-cooled wall sample tubes that had not been mechanically polished and had oxide skin and ash on the surface. The dimensions were 5mm×0.5mm×0.02mm, which were used to study the influence of oxide skin and ash residue on the sensitivity of eddy current detection on the original surface of water-cooled wall tubes. The experimental results show that the sensitivity can be guaranteed by the array eddy current test of the unpolished water-cooled wall sample tube. This method is used to accurately detect the thermal fatigue cracks in the water-cooled wall, ensuring high sensitivity and high detection efficiency.

3.4.2 Far-field eddies: The far field eddy current is a low frequency detector that penetrates the metal tube wall. The probe consists of an excitation coil and a detection coil, which receives the magnetic field generated by the self-excitation coil and returns after passing through the tube wall, and can detect the defects of the inner and outer walls of the tube with the same sensitivity, and is not limited by skin effect. It is not necessary to clean the ash and slag attached to the outer wall of the heating surface tube before the test begins. During the detection, the probe does not contact with the workpiece under inspection, and conduction coupling is not required.

For the water-cooled wall tube row to carry out far-field eddy current detection, the automatic crawler can be used to automatically record the detection data and detection location, so as to find the transverse crack and location of the water-cooled wall easily and quickly and collect the defect image. FIG.9 shows the water-cooled wall eddy current testing system, which can display the size, location,
depth and other information of internal and external wall corrosion reduction, spot corrosion, thermal fatigue crack and other defects in real time. It is recommended to choose at least 4 channels for testing the water-cooled wall tube of supercritical unit to ensure sufficient detection sensitivity. The distance between the probe and the surface of the water-cooled wall tube should be less than or equal to 0.75mm to ensure the sensitive capture of defect signals.

3.5 Other testing methods
PT method is also commonly used to detect surface opening defects, such as cracks, pores, etc. Its detection sensitivity is one order of magnitude lower than that of magnetic particle detection, and it needs mechanical grinding to remove oxide skin before detection, which leads to low detection efficiency, so it is not suitable for the investigation and detection of transverse cracks in large-area water-cooled walls. When it is found that the water wall is suspected of transverse crack by visual inspection or eddy current inspection, the local part can be rechecked by penetrant inspection method, which is easy to operate, the defect display is intuitive and convenient for high-altitude operation such as furnace.

RT technology is commonly used in the inspection of water wall installation welds and maintenance welds. It is difficult to locate the depth of defects in the radiographic testing technology [9], and there are disadvantages in the radiographic testing of crack like defects. On the one hand, the sensitivity of crack detection is low, on the other hand, it needs the cooperation of inside and outside the furnace to complete the detection work, so personnel radiation is inevitable.

4. Conclusions and Suggestions
The early failure of horizontal cracks in the water-cooled wall of the boiler of supercritical units mainly occurs between 4000h and 50000h. It is recommended to conduct non-destructive testing and troubleshooting of horizontal cracks in water-cooled wall tubes in the high-heat load area during the repair of unit A at the first and unit A at the second, so as to avoid frequent tube burst in this area.

Array eddy current and far-field eddy current detection in the service unit water cooling wall transverse crack, there is no need to remove pipe wall ash and slag and other foreign matters, to ensure high sensitivity, detection efficiency is high. And with the automatic crawling detection system, there is no need to set up scaffolding, suitable for large area transverse crack detection.

Peak-adjusting operation of the unit, rapid rise and fall of the boiler load, and drastic changes in the temperature of the water-cooled wall to the fire side wall, so the monitoring of the wall temperature should be strengthened according to the operation and maintenance conditions, and the monitoring and testing of the abnormal wall temperature area should be strengthened.

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