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Research Article

Failure Analysis of 600 MW Supercritical Boiler Water Wall

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Abstract: Boiler tube often causes abnormal boiler outage, bringing greater economic losses. This thesis mainly comes from the dynamics of boiler water, boiler furnace accident location of wall temperature distribution to explore the cause of the accident boiler. Calculation results show that the deformation will seriously reduce the boiler allowable maximum temperature difference between the screens. And the boiler is not over-temperature, low temperature difference between the screens, which have burst pipe. Analysis of the deformation of the boiler and propose solutions.

Keywords: Deformation, failure analysis, supercritical boiler, tube explosion

INTRODUCTION

The coal-fired power plants have dominated the main position of power generation in China (Cui, 2010). By the end of 2009, it's installed generating capacity has reached 10.5 billion kilowatts, in which the coal-fired power generation accounted for 72.3% (BaWei Company, 2009). Due to the needs of high efficiency and low pollution emission, the supercritical boiler has become an important clean coal-fired power generation technology, but the boiler's safety will directly impact on the security and stability of the other components (Zhou, 2006). The data show, among the accidents of Chinese coal-fired power generation, because of the shutdown, which is caused by the boiler accident, accounting for 40% and the all types of heating surface tubes accident is about 70% (Luo, 1981; Song, 1995). It shows that the destruction of the heating surface tubes is an important reason for thermal power plant accident shutdown.

The 3rd boiler of Jinzhushan power plant is the first 600 MW supercritical anthracite "W" flame boiler in the world and began to operate in December 2009. But the destructions of water wall tubes often happen since operating, so it has practical significance to research the failure mechanism of boiler water wall.

BOILER OVERVIEW

This 3rd boiler of Jinzhushan coal-fired power plant is produced by the Beijing Babcock and Wilcox. It use the Π type layout, single furnace, new concentrated EI-XCL burner, arch combustion and the Furnace use internally ribbed tube vertical rise Membrane water wall, circulation pump to start the system, once reheat and the thermostat addition to using coal/water and then also to use the flue gases allocation baffle, swing burner, spraying and so on. The boiler main parameters are in Table 1.

Table 1: Boiler main parameter

Project	BMCR	TRL	THA
Superheated steam flow/t/h	1900	18110	1677
Superheated steam outlet pressure/MPa	25.400	25.280	25.110
Superheated steam outlet temperature/°C	571	571	571
Reheat steam flow/t/h	1613	1535	1433
Reheater inlet steam pressure/MPa	4.632	4.402	4.119
Reheater outlet steam pressure/MPa	4.442	4.222	3.950
Reheater inlet/outlet steam temperature/°C	319.9/569	315.7/569	308.1/569
Boiler feed water temperature/°C	283	280	275

The boiler is a general rather poor equipment and it need to design a suitable boiler according to coal quality characteristics for different coals. This kind of coal designed for the boiler comes from the coal mine near the power plant. Considering changes in boiler coal and check its coal again. Coal characteristics of the boiler and checking coal characteristics are shown in Table 2.

It has 1562 water wall tube for The lower part and composed of 30 loops, Pipe specification φ 35×6.5 mm, the pitch of 55 mm, The water wall pipe material SA213T12, flat steel material for 15CrMo, the furnace water wall of lower all use the Optimization bulls threaded pipe (OMLR) and avoid the occurrence of deterioration of the heat transfer. In the middle it is composed of 110 Φ 133×20 mm material for 12Cr1MoVG connection tube to incorporated into the intermediate mixed set box. One thousand four hundred and ninety eight water wall tubes of Upper water wall compose 18 loops. Tube specifications is Φ 28×6 mm, material is 15CrMoG and the pitch is 55 mm, The flat

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Table 2: Boiler fuel characteristics

			Designed coal	Checking coal 1	Checking coal 2
Calorific as received	$Q_{net,\alpha r}$	MJ/kg	18.8437	16.9533	20.6277
Industrial elemental analysis (weight)					
Total moisture as received	M_t	%	9.3900	9.5300	9.0000
Air dried moisture	$M_{\alpha d}$	%	1.1200	0.8600	1.1800
Dry ash-free basis volatile	$V_{d\alpha f}$	%	7.0000	8.0000	6.0000
Receipt of ash	$A_{\alpha r}$	%	35.9900	41.0800	30.3300
Receive based carbon	$C_{\alpha r}$	%	49.6000	44.7100	55.5800
Hydrogen as received	$H_{\alpha r}$	%	1.7100	1.5000	1.5700
Receipt of oxy	$O_{\alpha r}$	%	1.5300	1.4000	1.4700
Receive base nitrogen	$N_{\alpha r}$	%	0.5800	0.9800	0.5500
Receive base sulfur	$S_{\alpha r}$	%	1.2000	0.8000	1.5000

Fig. 1: September 2009 accident pictures

Fig. 2: November 2010 accident pictures

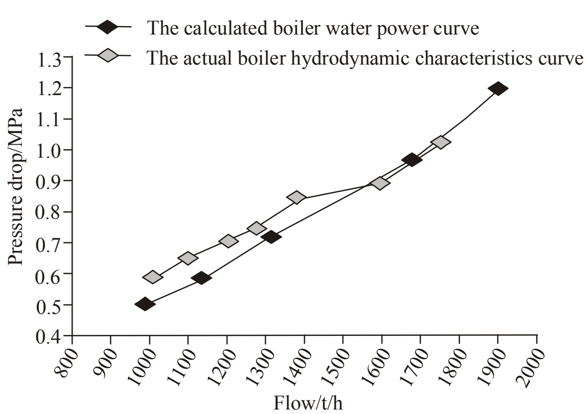

Fig. 3: Hydrodynamic characteristics curves of boiler

steel specifications is 8×27 mm and the material is 15CrMo, Upper furnace part use the internal thread pipe.

BOILER TYPICAL SQUIB SITUATION

Boiler furnace is in September 2009, as shown below, it is at the water wall middle of the 41 m elevation in the front wall and the water wall tube cracks 45 cm. Accident pictures in Fig. 1. Water wall tube has no significant rising crude. In November 2010, the water wall tube crack in the 38 m position in the back wall, Population explosion 10 mm, wide mouth 20 mm and no significant up rough. Accident pictures in Fig. 2.

Boiler hydrodynamic calculations: According to boiler hydrodynamic calculation standards in our country and refer to the former Soviet Union hydrodynamic calculation standards, Select several typical conditions (respectively the BMCR, TRL, 80% THA, 70% THA, 60% THA conditions) to calculate the boiler water wall voltage drop and to draw hydrodynamic characteristics curves and compared with the boiler water wall actual hydrodynamic characteristics curve (the actual data is the processed data in the DCS). The results are shown in Fig. 3.

Calculated pressure drop agrees well with the actual pressure drop on the whole. The slope of the curve of Boiler hydrodynamic characteristics is relatively large and generally does not appear hydrodynamic instability. But in the flow 1400-1500 t/h, when the separator outlet pressure is about 21.81 Mpa, In the pseudo-critical areas, the working fluid specific heat change greatly, under special circumstances may appear film boiling and may appear multivalent situation (the flow area slope is small and anti-disturbance ability is weak).

Boiler in traffic of 100% BMCR Firstly use average flow calculation and then do the flow curve Back calculation by the pressure drop. Obtained by calculating the front, rear, side walls single tube flow ratio is 1:1.01:1. This shows that the boiler flow is more evenly distributed.

The boiler tubes pulsating checking usually choose the boiler startup load and boiler minimum load condition to calculate. If the calculated mass flow rate is greater than the boiler limit velocity that the boiler does not occur pipes pulsating. Choose flow of 974,570 t/h to carry out inter tube calculation. Through lookup

Table 3: Tube pulse calibration

	Load	
Mass flow rate	60%THA (974t/h)	30%THA (570 t/h)
$(\rho w)_{jx}$ kg/m^2.s	126	175
(ρw) kg/m^2.s	1022	695

Nomographic to get limit flow rate and calculation coefficient, the calculation results are shown in Table 3.

Boiler wall temperature calculation: The highest point temperature of wall is calculated by using the following formula:

$$t = t_{gz} + \mu(r_1)\frac{\beta q^{\max}{}_w}{\alpha} + \mu(r_1)\frac{\beta q^{\max}{}_w}{(1+\beta)}\frac{2\delta}{\lambda}$$

where,

t : Wall positive temperature
β : Tube diameter ratio
q^{max} : Wall positive heat flux density
α : Coefficient of heat transfer to the working fluid from the inner wall
δ : Wall thickness
λ : Thermal conductivity of the tube
tgz : The temperature of the working fluid
u (r_1) : Shunt coefficient

The fin end temperature is calculated as follows:

$$t_g = t_{gz} + \mu_g q_{\max}\beta(\frac{\delta}{\lambda}\frac{2}{1+\beta} + \frac{1}{\alpha})$$

$$\mu_g = 0.35 + 0.1\frac{b}{d} + k_a k_\beta k_{s/d}$$

where,

t_g : The fins end of temperature
μ_g : Shunt coefficient
β : Tube diameter ratio
q_{max} : Wall positive heat flux density
α : Coefficient of heat transfer to the working fluid from the inner wall
δ : Wall thickness
t_{gz} : The temperature of the working fluid
b : Fin thickness
d : Tube diameter
k_α, k_β, $k_{s/d}$: Correction factor (Zhou, 2006)

According to the formula to Calculate Boiler in 100% condition, the largest and most dangerous area of the heat flux. The position of elevation is 40 m and the calculation results are shown in Fig. 4 to 9.

The calculation results show that the front and back walls of the boiler is the bimodal temperature field,

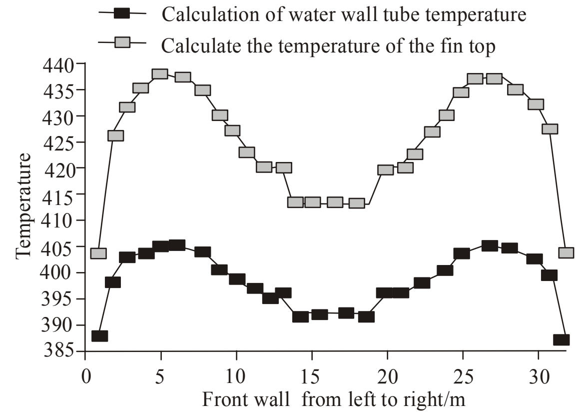

Fig. 4: Boiler wall temperature calculation

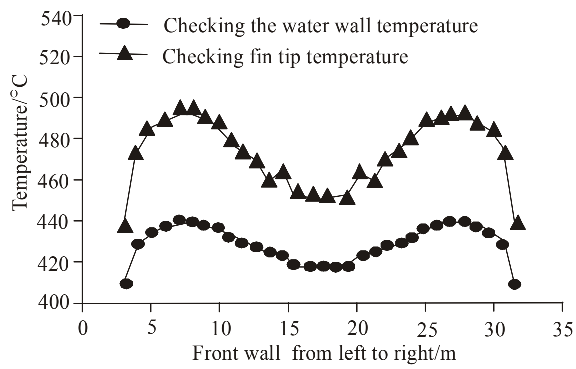

Fig. 5: Wall temperature in the boiler before checking calculations

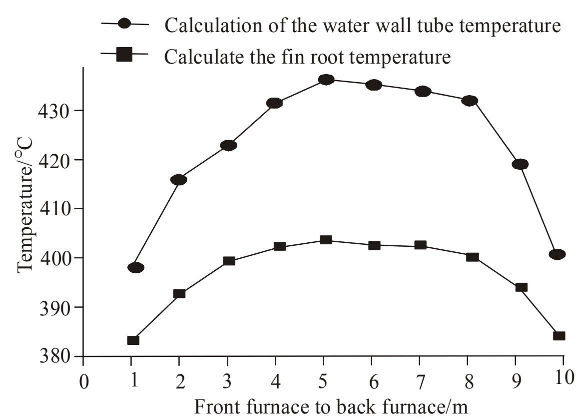

Fig. 6: Boiler side wall temperature calculation

and the side wall is the single peak temperature field. Before and after the wall about six meters away from the side walls on both sides is the highest temperature in the boiler and the Sidewall center position has the highest temperature. Wall temperature of the boiler is lower than the inner wall temperature about 10 to 50°C. As it is calculated that the working fluid temperature is lower than tube wall temperature, pipe working fluid temperature is higher than the outer wall temperature.

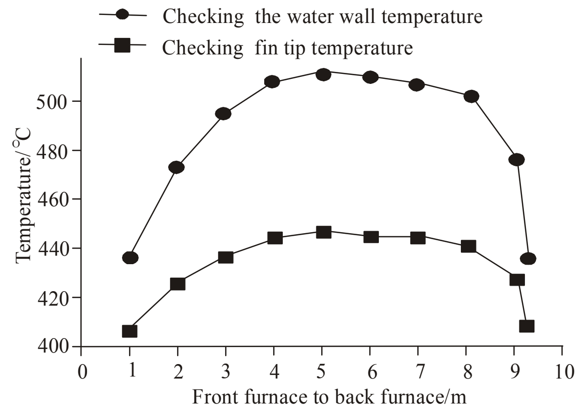

Fig. 7: Boiler side wall temperature check calculations

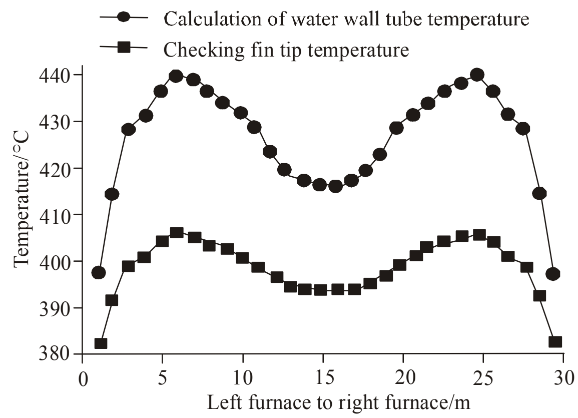

Fig. 8: The boiler wall temperature calculation results

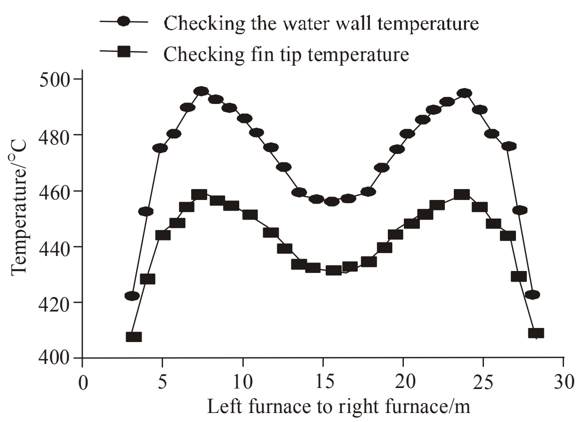

Fig. 9: Boiler wall temperature check calculations

Both inside and outside wall temperature difference is the biggest in the highest position of the center temperature. Front, rear and side walls all have the smallest temperature difference between the inside and outside wall of the corner position. The maximum wall temperature of boiler is about 420°C, even coupled with the maximum temperature of 50°C is only 470°C, The boiler calculation rupture strength temperature is the next furnace to 511°C, and the upper furnace to 492°C. Therefore boiler wall temperature does not exceed the temperature. The boiler Checking Calculation temperature is also lower than the boiler's calculation rupture strength temperature. Table 4 is the boiler furnace water wall operating parameters, when to DC process. As can be seen from the Table 4 boiler wall running temperature much lower than the design, there is no danger of over temperature, when boiler is running.

THE BOILER BURST PIPES REASON ANALYSIS

The squib positions concentrated in the 35-45 m where obvious deformation of the section, Fig. 10 and 11 is the basis of measurement of the upper furnace to the top position of 40 m in the deformation of the front and rear wall. Consider the deformation of the boiler water wall.

The water wall as one surrounded by a fixed sheet, the bending generated by thermal stress calculated by the following formula, the stress is the tangential stress:

$$\frac{1}{r} = \frac{\alpha t}{h}$$

$$\sigma_{\max} = \frac{\alpha t}{2} \frac{E}{1-\mu}$$

Among,

r : Radius of curvature, m
t : Inner and outer wall temperature difference, °C
σ_{max} : Bending produce the greatest internal stress, pa
α : Coefficient of linear expansion
μ : Elastic modulus

Upper furnace of the boiler approximately 14 m, every 2.9 m horizontal fixtures. If 10 mm as the actual amount of deformation aboving calculation, the temperature difference between the inner and outer walls of 117°C, tangential stress due to bending σ_{max} is 203 Mpa, it is significantly more than the boiler material furnace allowable stress (Upper furnace 511°C

Table 4: Furnace wall temperature design values and operating values

			80% THA	70% TA	60% THA	50% THA	40% THA	30% BMCR
Outlet tube wall temperature under the furnace	Design value		492	484	461	487	477	507
	Run value	Maximum	412	382	433	351	401	321
		Minimum	365	334	344	332	314	299
		Average	375	360	349	336	319	302
Outlet tube wall temperature upper furnace	Design value		483	486	482	492	499	501
	Run value	Maximum	403	403	415	359	355	303
		Minimum	373	357	343	330	314	298
		Average	388	373	372	333	319	300

Fig. 10: Boiler front wall deformation distribution

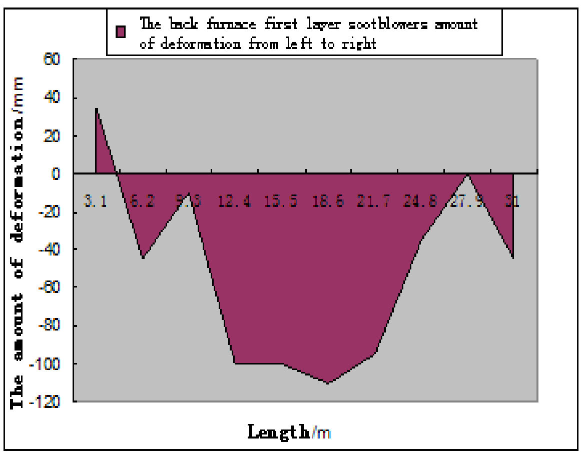

Fig. 11: Boiler back wall deformation distribution

allowable stress 80 Mpa, Upper furnace 492°C allowable stress of 90.3 Mpa), if 5 mm for the actual amount of deformation of the inner and outer wall temperature is 58°C, the bending stress is 95.8 Mpa, More than a boiler material allows the use of maximum stress, normal operation, inside and outside tube wall temperature does not exceed 30°C. The temperature of fin endpoint and tube does not exceed 50°C. The plate inner and outer walls of the actual temperature should be lower than the minimum of the two values that is lower than 30°C.

Consider the boiler bent by the impact of the boiler water wall tubes. Boiler strength adopt the third strength theory, Boiler axial to the most dangerous the direction of the third strength theoretical, tangential stress increases to over axial stress. According to the third strength theoretical maximum shear stress is the material cause of failure, the size of the maximum shear stress is $\tau_{max} = (\sigma_1 - \sigma_3) /2$, σ_3 is tangential stress, in this process unchanged, σ_1 is the axial stress original, tangential stress currently, σ_3 constant to make τ_{max} less than the boiler maximum allowable stress can only keep σ_1 constant large, σ_1 is composed of three parts: the boiler thermal stress, the curved shear stress and film stress, The size of the other two forces, boiler bent to form shear stress increases the boiler tube damage, we can only reduce the boiler temperature stress, reduce the allowable temperature difference.

This creates a temperature difference between the boiler screen did not exceed the boiler burst pipe allowable temperature difference. If calculated in accordance with the above formula, boiler bend increased by 3 mm, boiler screen temperature difference between allowable will be reduced to about 20°C. Actual wall temperature of the boiler is not in excess of the calculated temperature, but boiler actual shear force exceeds the calculated temperature or close to the calculated temperature of the stress causes creep acceleration during operation, resulting in the over-temperature creep phenomenon.

The reason of the pipe burst: The boiler water wall serious deformation, deformation water wall radial stress is greater than the axial stress, boiler as the stress increases between screen allows maximum temperature difference reduced, resulting in the boiler in the deformation of the large temperature difference between serious regional screen squib.

TO TAKE PRECAUTIONS

- **A reasonable temperature field:** From the boiler temperature distribution, the deformation of the front and back walls of the boiler is very serious and the side wall is almost no deformation. The front and back walls of the boiler have two highest temperature values, the side wall is only a maximum temperature. This shows that to some extent different deformation bimodal temperature field expansion lead boiler deformation. Consider the flame center closer to the center to form a side wall of a single peak.
- **To control the temperature difference between the boiler screen:** The temperature difference between the screen of the boiler recommended is 84-120°C. Consider the deformation of weakened to allow the temperature difference between the screen. In actual operation, to maintain the temperature difference between the outer wall of the screen less than 20°C or lower. This guarantees that the side near the fire of between the screen temperature below 70°C.
- **To monitor boiler outer wall temperature:** Boiler water wall tubes calculated rupture strength at temperatures under the furnace is 511°C, upper furnace is 492°C. Check Calculation of boiler water wall tube wall than the outer wall of the maximum temperature difference is back of the water wall, at 80°C. The front wall and side walls of the maximum temperature difference is 60°C.

The front side wall of the outer wall of the boiler's upper furnace should be controlled below 430°C, under furnace is lower than 450°C. The back side wall of the outer wall of the boiler's upper furnace should be controlled below 410°C, under furnace is lower than 430°C.

- **Replace the deformed tube:** Severely deformed under stress analysis pipe tangential stress increase, when it is greater than the axial stress of the boiler will reduce the boiler allows between screen temperature difference cause boiler force shear, creep acceleration, tube rupture. Replacement of deformed pipe to prevent pipe explosion from happening again.

CONCLUSION

Simplify the water wall to fixed flat, calculate the occurrence of severe deformation of boiler water wall. The results showed that the deformation will seriously reduce the boiler to allow the largest temperature difference between the screen. This leads to the boiler temperature difference between not over-temperature, low screen squib. Water wall deformation may be the boiler temperature difference too large between the inside and outside wall or horizontal water wall deformation varies. Replace the severe deformation water wall tube, to reduce operation allows the screen not higher than 70°C temperature difference, prevent to burst pipes happen again.

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