Evaluation of Service Life of Boiler Drum in Service Power Plant

Hui Li*, Yangyang Zhang[a], Yayong Qian[b], Li Zhang[c]

* 446556712@qq.com; [a] 380375852@qq.com; [b]719718712@qq.com; [c]542187412@qq.com

Gansu Electric Power Research Institute Technology Center Co., Ltd., Lanzhou, China

Abstract: This article aims to evaluate the service life of a steam drum in a power plant by conducting internal boiler inspections and combining existing fatigue life assessment methods and standards. Based on the evaluation results, targeted maintenance and preventive measures have been proposed, providing theoretical support and practical guidance for the safe operation of power plant boilers.

Keywords: steam drum; Defects; Life assessment

1 Preface

Power plant boilers are the core equipment of power production, and their operational safety and economy have a significant impact on the entire power production process. As one of the important components of power plant boilers, the steam drum is subjected to complex working conditions such as high temperature, high pressure, and high stress during operation, which can easily lead to low cycle fatigue and cause the failure of the steam drum [1] - [2], leading to serious accidents and affecting the operational efficiency and safety of the power plant. Therefore, Accurately evaluating and predicting the service life of steam drums is crucial.

2 Internal inspection of steam drum

2.1 Overview of boiler drum

The title is set 17 point Times Bold, flush left, unjustified. The first letter of the title should be capitalized with the rest in lower case. It should not be indented. Leave 28 mm of space above the title and 10 mm after the title.

1. The unit capacity is 300MW, the inner diameter of the boiler drum is 1743mm, the length of the cylindrical part is 17600mm, and the wall thickness is 145mm. It is composed of 6 cylinder bodies and 2 spherical heads, and the steel is BHW35 steel. The drum body includes 4 pieces Φ 588.8 ×60mm downcomer, 68 pieces Φ159e ×18mm, 8 pieces Φ 133 ×14mm inlet pipe, 18 pieces Φ 159 × 18mm outlet pipe and other main connecting pipe sockets;
2. As of September 2023, it has operated for a total of 200114 hours, with a total of 287 starts and stops, including 97 cold starts and 190 hot starts and stops;

IDEE 2023, November 24-26, Zhengzhou, People's Republic of China

DOI 10.4108/eai.24-11-2023.2343466

2.2 Boiler drum inspection and testing items

1. Macroscopic inspection: Macroscopic inspection of the steam drum body, steam and water inlet pipes, outlet pipes and downcomers, water supply pipes and other connecting pipes, as well as internal inspection of the surface condition of welding seams and the connection of internal accessories, no abnormalities were found;As of September 2023, it has operated for a total of 200114 hours, with a total of 287 starts and stops, including 97 cold starts and 190 hot starts and stops;
2. Magnetic particle testing: Surface inspection conducted spot checks on the circumferential welds of the head on both sides of the steam drum, 2 longitudinal welds, 10 corner welds of the steam and water outlet pipes, 10 corner welds of the steam and water inlet pipes, 3 corner welds of the descending pipes, 2 corner welds of the water supply pipes, and 2 corner welds of the safety valve seat, and no abnormalities were found;
3. Ultrasonic testing: spot check the circumferential welds and two longitudinal welds on both sides of the head, and no abnormalities were found in the spot check parts;
4. Metallographic inspection: One spot inspection was conducted on the weld seam of the A-side sealing head. The metallographic structure is pearlite and bainite, with banded structure and grain size of 6-7 grades;
5. Hardness inspection: One spot check was conducted on the weld seam of the A-side sealing head, and the average hardness value was 191HB;
6. Thickness measurement: Wall thickness measurements were conducted on the circumferential welds on both sides of the steam drum head, 2 longitudinal welds, 10 steam and water outlet pipes, 10 steam and water inlet pipes, 3 downcomers, and 2 water supply pipes. The measurement results met the minimum required wall thickness requirements.

3 Temperature field and stress analysis of steam drum

3.1 Analysis and calculation of temperature field

Looking up the boiler heating curve, it can be seen that the initial heating rate is 0.33~1.1 ℃/min. After ignition, the heating rate is controlled by the pressure rise rate. In the initial stage of combustion, weak combustion, uneven heating of the evaporation heating surface, and water circulation not yet established properly, it is easy to cause large temperature differences in the steam equipment, especially in the steam drum. Therefore, in the initial stage of pressure rise, it is necessary to strictly control the heating rate.

During normal operation of the boiler drum, the temperature difference between the inner and outer walls, as well as the temperature difference between the upper and lower walls, is relatively small, and the generated thermal stress can be ignored. However, during rapid startup and shutdown and significant load changes, the pressure and temperature inside the drum also change, causing significant thermal stress to be generated in the inner and outer walls, as well as the upper and lower walls of the drum, leading to fatigue damage to the drum[3]. When the temperature of the drum changes, There are three types of temperature differences: radial temperature difference (caused by temperature gradient along the wall thickness direction); Circumferential temperature difference (caused by temperature non-uniformity in the circumferential direction); Axial temperature difference (caused by uneven temperature along the axis of the steam drum)[11].

3.1.1 Radial inner and outer wall temperature difference

$$\Delta t_r = t_0 - t_i = -\frac{C_t \delta^2 \upsilon}{a_t}(1 - e^{-\chi t/\tau}) \qquad (1)$$

In the formula, t_0 :Drum outer wall temperature, (℃)

t_i :Inner wall temperature of steam drum,(℃)

C_t :Structure coefficient of radial wall temperature difference

δ :Nominal thickness of steam drum,(mm)

υ :Temperature change rate of working fluid,(℃/min)

a_t : Calculate the thermal diffusivity of the cylinder material at the highest wall temperature under working conditions,(mm^2/min)

e : Base of natural logarithm

χ :Temperature damping coefficient

τ :Time constant(min)

Table 1 Physical Properties of BHW35 Steel

Temperature (℃)	20℃	100℃	200℃	300℃	400℃	500℃
Density ρ(t/m^3)	7.85	7.82	7.79	7.76	7.72	7.69
Elastic modulus E(×10^{5}MPa)	2.16	2.11	2.04	1.96	1.87	1.76
Thermal conductivity λ [W/(m.K)]	36.8	38.9	38.9	38.1	36.8	35.2
specific heat capacity at constant pressure c_p [KJ/(kg.K)]	/	0.486	0.498	0.519	0.532	0.548
linear expansion coefficient a_l(×10)$^{-6}$℃$^{-1}$	/	12.2	12.8	13.4	13.9	14.3

Table 2 Calculation results of radial inner and outer wall temperature difference of steam drum under operating conditions

Working condition	Temperature variation(℃)	Pressure changes(MPa)	Drum load change time (min)	Drum heating rate(℃/min)	Radial inner and outer wall temperature difference(℃)
Cold start stop	50-365	0.5-19.74	360-480	1.46	23.142
Hot start stop	230-365	4-19.74	90-120	1.46	23.142

According to formula (1) and the physical performance parameters of BHW35 material, calculate the radial inner and outer wall temperature difference of the steam drum under normal operating conditions, as shown in Tables 1 and 2.

3.1.2 Circumferential temperature difference between upper and lower walls

The metal components on the upper part of the steam drum come into contact with steam, forming the steam space, while the metal components on the lower part come into contact with water, forming the water space. Due to the different heat release coefficients of steam and water on the inner wall of the steam drum, the temperature distribution between the upper and lower walls of the steam drum is uneven, forming a temperature difference [4]. The circumferential temperature difference of the steam drum is very complex, and is related to the internal structure of the steam drum, the water circulation process of the steam drum, start stop, and operation factors. Relevant literature [5] points out that, The thermal stress caused by the temperature difference between the upper and lower walls of the steam drum in the drum body is mainly axial stress, and the tangential and radial stresses are both one order of magnitude lower than axial stress. The temperature difference between the upper and lower walls and the influence of temperature difference thermal stress can be disregarded. According to the operating regulations of the boiler in this power plant, it is stipulated that during the heating and pressure boosting stage of the boiler, the temperature difference between the inner and outer walls of the upper and lower walls of the drum, as well as the wall temperature difference between any two points, should not exceed 40 ℃. If it exceeds this, the reason should be analyzed in a timely manner, Adjust combustion, strictly control the speed of temperature rise and pressure rise, and appropriately strengthen the drainage of the lower header[12]-[13]. If the wall temperature difference continues to increase, the temperature rise and pressure rise should be stopped immediately, and the pressure rise should be resumed after normal operation. Considering safety margin, 40 ℃ should be taken for calculating valley stress and 10 ℃ for calculating peak stress.

3.2 Stress analysis and calculation

During the operation of a steam drum, stress concentration usually occurs at the openings, bridges, and other structural discontinuities between the cylinder and the head, downcomer, and water supply pipe. In fatigue calculation, the maximum stress concentration location should be determined first, usually located at the inner corner of the larger opening in the cylinder. After comprehensive comparison of the structural arrangement of the steam drum, the most severe stress concentration is located at the inner corner of the downcomer pipe inner wall caused by geometric discontinuities [6].

3.2.1 Finite element stress analysis

Using ANSYS to analyze the local area of the steam drum using linear statics, a section of the cylinder with a descending pipe seat is selected. The maximum pressure reached by the steam drum under normal operating conditions is 19.74 MPa. Without considering fixed constraints, axial constraints, and rotational constraints, the structure is not subjected to additional loads and constraints. Applying a pressure load of 19.74 MPa can obtain the overall displacement cloud map and equivalent stress diagram of the structure, as shown in Figure 1 As shown in Figures 2 and 3.

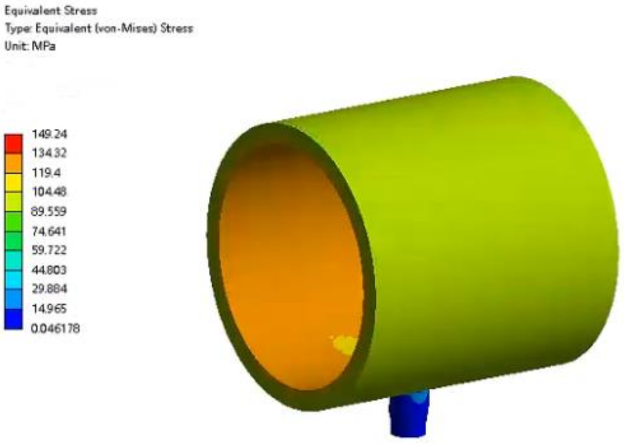

Figure 1 Overall Equivalent Stress Diagram of Steam Drum

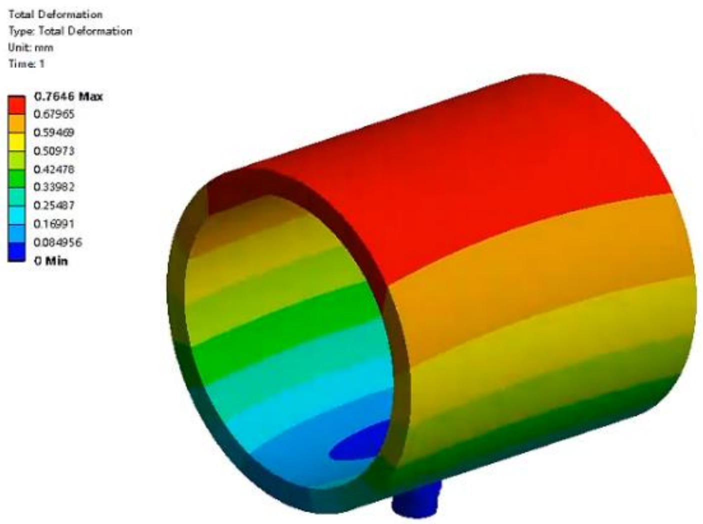

Figure 2 Overall deformation of the steam drum

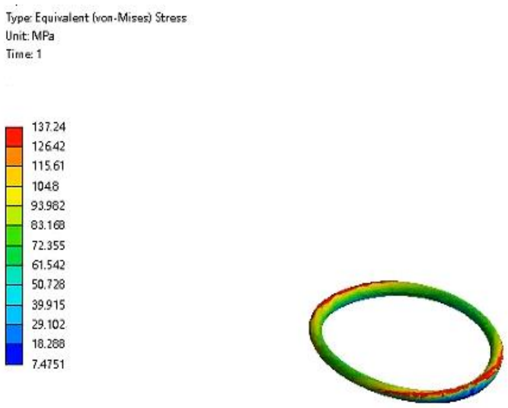

Figure 3 Equivalent Stress Diagram of Downcomer Fillet Weld

From the results, it can be seen that under the maximum internal pressure of the steam drum, the maximum equivalent stress of the cylinder is about 149.24MPa, with uniform stress distribution and stable structure. The maximum stress of the fillet weld of the steam drum is about 137.24MPa. Compared to the cylinder area, the stress concentration coefficient at the downcomer pipe seat is relatively high, and the stress is mainly composed of circumferential stress components.

3.2.2 Stress calculation of steam drum

According to the calculation formulas for thin film stress, radial temperature difference stress, circumferential temperature difference stress, and stress amplitude in Appendix A of GB/T16507.4-2022, the results are shown in Tables 3 and 4.

Table 3 Summary of Stress Calculation Results (MPa)

Working condition			Cold start stop	Hot start stop
Internal stress	Circumferential σ_{np}	Peak value	407.241	407.241
		Valley value	0	36.114
	Axial σ_{zp}	Peak value	-26.002	-26.002
		Valley value	0	-2.777
	Normal σ_{rp}	Peak value	-17.350	-17.350
		Valley value	0	-1.55
Radial temperature difference thermal stress	Circumferential σ_{np}	Peak value	123.120	123.120
		Valley value	-123.120	-123.120
	Axial σ_{zp}	Peak value	0	0
		Valley value	0	0
	Normal σ_{rp}	Peak value	0	0
		Valley value	0	0

Circumferential temperature difference thermal stress	Circumferential σ_{np}	Peak value	-6.884	-6.884
		Valley value	-15.442	-15.442
	Axial σ_{zp}	Peak value	0	0
		Valley value	0	0
	Normal σ_{rp}	Peak value	0	0
		Valley value	0	0

Table 4 Stress synthesis calculation results under different working conditions (MPa)

Working condition			Cold start stop	Hot start stop
Composite principal stress	Circumferential σ_{nj}	Peak value	523.477	523.477
		Valley value	-138.562	-138.114
	Axial σ_{zj}	Peak value	-26.002	-26.002
		Valley value	0	-2.777
	Normal σ_{rj}	Peak value	-17.350	-17.350
		Valley value	0	0
Difference in principal stress	$\sigma_{nr.1}$		549.479	549.479
	$\sigma_{zr.1}$		-8.652	-8.652
	$\sigma_{rn.1}$		-523.477	-523.477
	$\sigma_{nz.2}$		-138.562	-135.337
	$\sigma_{zr.2}$		0	-2.777
	$\sigma_{rn.2}$		138.562	138.114
Fluctuation range of stress difference	$\Delta\sigma_{nz}$		688.041	684.816
	$\Delta\sigma_{zr}$		8.652	5.875
	$\Delta\sigma_{rn}$		662.039	661.591
Range of alternating stresses			688.041	684.816
Stress amplitude			344.021	342.408

4 Low cycle fatigue life loss

In the calculation of the low cycle fatigue life of the steam drum, the fatigue design curve provided in GB/T16507.4-2013 is used. The stress amplitude of the steam drum under cold, hot and other working conditions is calculated, and its corresponding fatigue life N is found on the fatigue curve. Based on the actual start and stop times ni of the steam drum under various working conditions, the damage rate ni/N under various working conditions is calculated, using the safety criterion of cumulative damage, Calculate the total cumulative fatigue life loss, the calculation results are shown in Table 5.

Table 5 Calculation Results of Low Cycle Fatigue Loss under Various Working Conditions

Working condition	Corrected stress amplitude	Actual number of starts and stops	Number of cycles required	Total damage rate
Cold start stop	378.423	97	About 4000	2.43%
Hot start stop	376.365	190	About 4000	4.75%
Cumulative damage		7.18%		

5 Analysis of evaluation results and suggestions

According to DL/T 654 "Technical Guidelines for Life Assessment of Thermal Power Units" and GB/T 16507.4-2013 "Strength Calculation of Water Tube Boilers - Pressure Components", a fatigue life assessment was conducted on the steam drum of the power plant boiler[8] -[10]

1) Taking the inner corner of the axial section of the descending pipe seat of the steam drum as the assessment point, the fatigue life loss of the steam drum under cold start stop and hot start stop conditions was analyzed through calculation. The cumulative fatigue life loss was 10%, which was less than the upper limit value specified in the standard by 75%;

2) As of September 2023, the steam drum has been in operation for 26 years, with 97 cold start and stop cycles and 190 hot start and stop cycles, with a cumulative fatigue damage rate of 7.18%. If it operates according to previous operating patterns, with annual cold start and stop, hot start and stop, and hydraulic testing, the fatigue loss and remaining fatigue life of the steam drum can meet the needs of the next two major repair cycles or more than 10 years of operation;

3) In the later service process, it is recommended to strengthen the inspection and data management of the steam drum in accordance with relevant regulations (DL/T 438, DL/T 440). During each major overhaul, the focus should be on inspecting the inner corners and fillet welds of the lower pipe seat[14].

6 Conclusion

This article evaluates the remaining life of a boiler drum in a power plant through on-site inspection and testing, based on relevant standards. By analyzing and calculating the stress of the drum, estimating the low cycle fatigue life loss, the remaining life of the drum is given. This has important practical significance for the operation and maintenance of the power plant. By accurately evaluating the low cycle fatigue life of the drum, the power plant can take timely measures to ensure the safe operation of the drum and reduce accident risks, And improve the operational efficiency and reliability of the power plant.

References

[1] Wang Ke, W. (2021) Assessment of the Remaining Life of the Steam Drum of a 600MW Subcritical Control Cycle Boiler Special equipment safety technology, 5:1-5.

[2] Yue Zengwu, Y. (2023) Life assessment of high-temperature headers in thermal power unit boilers Shandong Electric Power Technology, 50 (306): 77-81.

[3] Li Liren, L. (2009) High temperature creep fatigue life design calculation method for boiler pressure components Journal of Power Engineering, 29 (5): 409-416.

[4] Caiwenhe, C. (2009) failure and supervision of important metal parts of power station China Electric Power Press Beijing.

[5] Zheng siding, Z. (1998) temperature field and thermal stress analysis and low cycle fatigue design of boiler drum wall of peak shaving unit Power engineering, 6:23-27.

[6] Shenjianping, S. (2012) study on low cycle fatigue life of 400t/h boiler drum East China power, 7:1222-1225.

[7] GB/T16507.4-2022, water tube boilers Part 4: strength calculation of pressure components.

[8] GB/T30580-2014, technical guidelines for life assessment of main pressure bearing components of utility boilers.

[9] DL/T654-2019, technical guidelines for life assessment of thermal power units

[10] J Taler，B Weglowski，W Zima，et al. Analysis of ThermalStresses in a Boiler Drum During Start -up [J].Journal ofPressure Vessel Technology，1999，121:84-91.

[11] A. Saad Abou-elazm, Failure investigation of secondary super-heater tubes in a power boiler[J], Engineering Failure Analysis, 2008, Vol.16(1)

[12] D. Ghosh, High Temperature Corrosion Failure of a Secondary Superheater Tube in aThermal Power Plant Boiler[J], High Temperature Materials and Processes, 2009, Vol.28 (1-2)

[13] K. Sawada T. Ohba,H. Kushima. Effect of microstructure on elastic propérty at high temperatures in ferritic heat resistant steels[J],. Materials Science and Engineering, A394（2005)