Research on Dynamic Characteristics of Furnace in 670 t/h Ultra-high Pressure Pulverized Coal Furnace after Burner Transformation

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Abstract The power field characteristics of a 670t/h boiler in a power plant were studied after the burner transformation. The results show that the size of the aerodynamic fluid in the hearth of the burner is appropriate, the furnace is full, and the center of the strong wind ring is basically in the center of the hearth. The wind speed of the wall around the water-cooled wall is within a reasonable range; there is a certain wind speed deviation on the side, and the angle of the SOFA reverse wind can be adjusted appropriately to eliminate the residual rotation existing at the furnace outlet. The research results can provide a reference for the transformation of burners of the same type.

1 Introduction

Due to the country's continuous improvement of air pollutant emission standards for thermal power plants, a $2 \times 220\text{MW}$ unit in a power plant in Shandong could not meet the national requirements for environmental protection standards. Therefore the power plant has modified the boiler burner to meet the national requirements for NO_x emission standards. The combustion effect of the boiler mainly depends on the aerodynamic characteristics of the furnace [1~2]. Due to the larger burner layout and air distribution after the transformation, in order to understand the flow characteristics of the fluid in the furnace after the transformation of the burner, the furnace cooling aerodynamic field test and related research are performed. It is hoped to provide a reference for the hot operation of the boiler and the modification of the related model boiler burners.

2 Device overview

The boiler of a power plant is a WGZ 670 / 13.7-6 ultra-high pressure, primary reheat, natural circulation, single furnace, balanced ventilation, negative pressure combustion, solid slagging, and II-type pulverized coal boiler produced by Wuhan Boiler Factory. It adopts a four-corner tangential combustion method. The pulverizing system adopts a positive pressure direct blowing type. The powder is fed by a single fan. It is equipped with five MPS-212 medium-speed coal mills.

According to the characteristics of the boiler and the characteristics of the actual coal type, the current international advanced and mature multi-air stage low NO_x combustion technology (MAS-LNCT technology)

will be used to comprehensively transform the existing burner. The specific transformation plan is as follows: (1) Add two sets of SOFA burners above the main burner. (2) The air volume of the secondary air nozzles has been adjusted, and all secondary air nozzles have been re-optimized and replaced. The secondary air is arranged with double nozzles. The design parameters before and after the burner modification are shown in Table 1.

Table 1 Burner Transformation Design Parameters

Project	unit	MCR (Before Transformation)	MCR (After transformation)
Primary wind rate	%	35.56	35.56
Secondary wind rate	%	60.44	30.44
Air leak	%	4	4
SOFA	%	/	30
Primary air temperature	°C	65	70
Primary wind speed	m/s	25	28
Secondary air temperature	°C	290	317
Secondary wind speed	m/s	55	48
SOFA wind temperature	°C	/	317
SOFA wind speed	m/s	/	48
Hearth width	m	12.72	12.72
Hearth depth	m	12.72	12.72

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3 Principle of Dynamic Field Test

According to similar principles, the cold aerodynamic field test in a furnace should follow the following principles^[3]:

1 Geometrically Similar

Due to the cold and hot tests are performed on the same boiler, they meet the conditions of geometric similarity.

2 The Aerodynamic Field is in the Self-mode Area

When the boiler runs stably, the airflow conditions in the furnace belong to the stable forced motion of viscous fluids that do not isothermally, and the Reynolds number plays a major role in the flow process: $Re = \omega d / \nu$.

The so-called air movement state entering the self-modulation zone means that when Re is greater than a certain value, the inertial force becomes the decisive factor, and the influence of the viscous force can be ignored. Therefore, the trajectory of the air particle is mainly dominated by inertial force and is no longer affected by the Re value. For most boilers, $Re \geq 1 \times 10^5$ can enter the self-mold area.

3 Similar boundary conditions

The similar boundary conditions mean that the flow ratio of each gas entering the furnace through the burner under the hot condition is equal to the momentum ratio of each gas flow under the cold condition.

4 Test results and analysis

4.1 Primary wind leveling

Start the induced draft fan, supply blower and primary fan, and control the wind speed of the powder outlet pipe at the online wind speed of about 20 m/s ~ 25 m/s. The furnace negative pressure is holding -50 Pa to 100 Pa. The tester measures the local atmospheric pressure, temperature and humidity, and uses a calibrated pitot tube to measure the dynamic pressure, static pressure, and temperature on the powder tube according to the equal cross-sectional area method, and calculates the actual powder tube wind speed at the mill outlet. According to the wind speed deviation of each angle of each burner, adjust the adjustable shrinkage opening to control the wind speed deviation within the range of $\pm 5\%$. The calculation results and adjustment data are shown in Table 2 ~ Table 6.

Table 2 Recording Test Data for Uniformity Adjustment of Primary Air in Mill A

The first measurement				
shrinkage opening (%)	A1 (100)	A2 (100)	A3 (100)	A4 (100)
actual wind speed (m/s)	22.5	24.1	22.2	21.2
average wind speed (m/s)	22.5			
deviation (%)	0	7.1	-1.3	-5.8
The second measurement (A2 shrink hole closes 10 buckles)				
shrinkage opening	A1	A2 (90)	A3	A4

(%)	(100)	(100)	(100)	(100)
actual wind speed (m/s)	25.1	24.7	24.5	22.7
average wind speed (m/s)	24.3			
deviation (%)	3.5	1.9	1.0	-6.4
The third measurement (A1, A2, A3 shrink holes each closed 10 buckles)				
shrinkage opening (%)	A1 (90)	A2 (80)	A3 (90)	A4 (100)
actual wind speed (m/s)	22.1	22.1	22.5	22.6
average wind speed (m/s)	22.3			
deviation (%)	-1.0	-1.0	0.8	1.2

Table 3 Recording Test Data for Uniformity Adjustment of Primary Air in Mill B

The first measurement				
shrinkage opening (%)	B1 (100)	B2 (100)	B3 (100)	B4 (100)
actual wind speed (m/s)	25.7	27.5	24.2	20.6
average wind speed (m/s)	24.5			
deviation (%)	4.9	12.2	-1.2	-15.9
The second measurement (B1 shrink hole closes 10 buckle, B2 shrink hole closes 15 buckle, B3 shrink hole closes 10 buckle)				
shrinkage opening (%)	B1 (90)	B2 (85)	B3 (90)	B4 (100)
actual wind speed (m/s)	24.3	24.5	22.5	21.6
average wind speed (m/s)	23.2			
deviation (%)	4.6	5.5	-3.1	-7.0
The third measurement (B1 and B2 shrink holes each with 10 buckles)				
shrinkage opening (%)	B1 (80)	B2 (75)	B3 (90)	B4 (100)
actual wind speed (m/s)	24.5	25.0	23.7	22.4
average wind speed (m/s)	23.9			
deviation (%)	2.5	4.6	-0.8	-6.3
The fourth measurement (B1 shrink hole close 5 buckle)				
shrinkage opening (%)	B1 (75)	B2 (75)	B3 (90)	B4 (100)
actual wind speed (m/s)	24.5	25.0	23.7	23.2
average wind speed (m/s)	24.1			
deviation (%)	1.7	3.7	-1.7	-3.7

Table 4 Recording Test Data for Uniformity Adjustment of Primary Air in Mill C

The first measurement				
shrinkage opening (%)	C1 (100)	C2 (100)	C3 (100)	C4 (100)
actual wind speed (m/s)	24.4	23.9	21.1	22.9
average wind speed (m/s)	23.1			
deviation (%)	5.7	3.6	-8.6	-0.8
The second measurement (C1 and C2 shrink holes each with 10 buckles)				
shrinkage opening (%)	C1 (90)	C2 (90)	C3 (100)	C4 (100)
actual wind speed (m/s)	23.9	22.8	22.6	23.3
average wind speed (m/s)	23.2			
deviation (%)	3.2	-1.5	-2.4	0.6

Table 5 Recording Test Data for Uniformity Adjustment of Primary Air in Mill D

The first measurement (D1 shrink hole closes 20 buckle, D2 shrink hole closes 10 buckle, D4 shrink hole closes 25 buckle)				
shrinkage opening (%)	D1 (80)	D2 (90)	D3 (100)	D4 (75)
actual wind speed (m/s)	22.4	24.4	23.0	23.2
average wind speed (m/s)	23.3			
deviation (%)	-3.7	4.9	-1.1	-0.2

Table 6 Recording Test Data for Uniformity Adjustment of Primary Air in Mill E

The first measurement (E1 shrink hole closes 20 buckle, E2 shrink hole closes 10 buckle, E4 shrink hole closes 10 buckle)				
shrinkage opening (%)	E1 (80)	E2 (90)	E3 (100)	E4 (90)
actual wind speed (m/s)	21.8	21.6	20.9	21.5
average wind speed (m/s)	21.5			
deviation (%)	1.6	0.7	-2.6	0.2

It can be known from Tables 2 to 6 that the average primary wind speed of each layer after the test leveling is between 21.5 and 24.5, and the deviation of the wind speed of each layer is less than 5%. The wind speed at the four corners is relatively uniform, which is conducive to burning in the furnace.

4.2 Measurement of Strong Wind Ring in Layer B of the Furnace

On the level of the center-line of the primary air vent in layer B, four water-cooled wall centers were found on the horizontal plane, forming a “cross” intersection in the

furnace. The tangential wind speed was measured and recorded every 400mm from the center of the furnace along the “cross” crossing line. The wind speed measurement results of the strong wind ring in layer B are shown in Figure 1 and Table 7.

Figure 1 Schematic diagram of layer B strong wind ring**Table 7** Wind Speed Measurement Results of Strong Wind Ring in Layer B

Hearth Center → Left Wall (m/s)	Hearth Center → Back Wall (m/s)	Furnace Center → Right Wall (m/s)	Furnace Center → Front Wall (m/s)
1.8	2.1	2.6	2.4
2.3	1.7	4.1	3.0
3.4	3.0	4.6	3.8
3.9	5.5	6.1	4.8
3.0	5.9	7.3	4.6
5.8	7.3	8.2	6.8
4.8	6.9	9.3	7.7
8.4	7.5	8.5	7.9
9.7	9.3	8.1	8.3
7.1	8.6	6.6	5.8
5.3	6.6	7.6	4.9
4.0	4.4	6.7	4.0
5.8	3.9	4.4	4.2
5.0	3.8	3.5	4.4

The width and depth of the hearth are 12.72m, as shown in the measurement data of Figure 1 and Table 7. The diameter of the strong wind ring of layer B along the depth and width of the boiler is 8.48m. The maximum wind speed of the strong wind ring cross is 9.7m/s, which is the strong wind ring cross near the left wall; the highest wind speed of the wind ring cross near the front wall is slightly lower, which is 8.3m/s. The center of the tangent circle is basically coincident with the center of the hearth. The diameter of the tangent circle is appropriate and the filling degree is good, which indicates that the nozzle airflow does not deviate^[4], and the four corner burners have uniform air volume and air velocity distribution.

4.3 Adhesive Wind Measurement

Select a measurement point every 800mm near the water-cooled wall around the B burner layer (about 0.2m away from the wall), and use the anemometer to measure the wind speed on the wall. The wind speed measurement results of the B-layer wall are shown in Table 8 and the schematic diagram is shown in Figure 2.

Table 8 Wind Speed Measurement Results of Layer B

Horn 1 → Horn 2 (m/s)	Horn 2 → Horn 3 (m/s)	Horn 3 → Horn 4 (m/s)	Horn 4 → Horn 1 (m/s)
3.2	2.5	3.2	4.4
3.7	3.7	4.2	4.2
3.0	2.1	3.2	3.9
2.3	2.9	3.4	3.4
3.2	4.1	4.0	2.1
3.6	3.7	4.0	3.0
3.1	4.1	3.6	3.9
3.3	4.3	3.9	3.6
4.1	3.8	2.3	4.6
3.8	4.4	4.1	3.4
4.1	5.2	3.8	3.2
2.1	3.1	4.6	3.0
2.0	2.1	2.8	1.5
3.5	2.1	1.4	3.0
2.1	3.0	1.2	1.9

Figure 2 Schematic Diagram of Wind Speed on the B-layer Wall

As shown in Figure 2 and Table 8, most of the wall-mounted wind speed around the furnace wall is within a reasonable range of 2m/s ~ 3m/s. The highest wall-mounted wind speed on the front wall is 4.6m/s, the highest wall-mounted wind speed on the back wall is 5.2m/s, the highest wall-mounted wind speed on the left wall is 5.2m/s, and the right-wall water-mounted wall speed is 4.6m/s.

4.4 Wind Speed Measurement of Horizontal Flue at Furnace Exit

After the modification, the burner was added with a SOFA tuyere. In order to reduce the residual rotation of the furnace outlet, the burner tangent to the main combustion area has a reverse cut angle of 14°. During the test, the wind speed at the furnace outlet was measured, and the measurement results are shown in the following table:

It can be seen from Table 9 that there is a certain wind speed deviation in the left and right sides of the horizontal flue along the width direction. Due to the residual rotation of the upward rising airflow in the furnace to the furnace exit, there is a fluid velocity deviation on the left and right sides of the horizontal flue^[5]. Air velocity deviation will cause deviation of boiler exit steam temperature, or even part of super-heater-tube bundle over-temperature. Therefore, the angle of SOFA inverse wind should be appropriately adjusted to eliminate residual rotation at the exit of the furnace and make the horizontal flue wind speed distribution uniform.

Table 9 Wind Speed Measurement Results of the Left and Right Sides of the Horizontal Flue of the Furnace

Position on horizontal flue section	Right average wind speed (m / s)	Left average wind speed (m / s)	Right to left wind speed ratio
Upper	3.23	2.96	1.09
Middle	3.45	3.14	1.10
Lower	3.66	3.52	1.04

5 Conclusions and Suggestions

(1) After the adjustable shrinkage opening is adjusted, the primary powder pipe wind speed deviation of all grinding outlets is controlled within the range of 5%, which ensures the uniformity of the amount of powder with the four corners and the primary air momentum, laying a basis for reducing thermal deviations and full combustion. However, after the boiler is started, the primary airflow changes into a gas-solid two-phase flow, which causes local wear and tear on the pipes to be inconsistent, resulting in an uneven primary air speed. Therefore, it is recommended to perform hot air leveling as soon as possible after the boiler has started stable operation to reduce the thermal deviation of the flue gas in the furnace and ensure the economical and safe operation of the boiler.

(2) The measurement results of the strong wind ring in the B-layer furnace show that the size of the fluid circle in the furnace is appropriate after the burner reformation, and the furnace is full. The strong wind ring is counterclockwise (viewed from the top to the bottom) and has a diameter of 8.48m. The center of the strong wind ring is located approximately in the center of the hearth, slightly to the left wall. The maximum wind

speed of the strong wind ring cross is 9.7m/s, which is the strong wind ring cross near the left wall; the highest wind speed of the wind ring cross near the front wall is slightly lower, which is 8.3m/s.

(3) The measurement results of the B-layer closing-to- wall air show that most of the wall-mounted wind velocity of the water-cooled wall in the furnace after the burner modification is within a reasonable range of 2.0m/s-3.0m/s. The highest wall-mounted wind speed of the front wall is 4.6m/s, the highest wall-mounted wind speed of the back wall is 5.2m/s, the highest wall-mounted wind speed of the left wall is 5.2m/s, and the highest speed of the right-wall water-mounted wall is 4.6m/s.

(4) After the burner is reformed, there is a certain wind speed deviation in the left and right sides of the horizontal flue along the width direction. Due to the residual rotation of the upward rising airflow in the furnace to the furnace exit, there is a fluid velocity deviation on the left and right sides of the horizontal flue. Air velocity deviation will cause deviation of boiler exit steam temperature, or even over-temperature of part of super-heater-tube bundle. Therefore, the angle of SOFA inverse wind should be appropriately adjusted to eliminate residual rotation at the exit of the furnace and make the wind speed of the horizontal flue uniform.

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