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Research on Flow Path Transformation Scheme for 300MW Subcritical Units in Thermal Power Plants

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Abstract: Taking a 300MW subcritical unit as an example, based on the operating data of the unit, three schemes for steam turbine flow modification were proposed. A comparative analysis was conducted on the technical parameters, energy-saving effects, and economic benefits of various schemes before and after the renovation, and recommended schemes were provided.

Keywords: Subcritical Unit; Steam Turbine Flow Modification; Energy Conservation.

1. Introduction

China uses a large amount of coal for power generation, and the overall power generation efficiency of thermal power enterprises is not high; On the other hand, the growth of thermal power units in recent years has also brought a series of environmental problems [1]. In order to improve the power generation efficiency of thermal power units and solve environmental problems, the National Development and Reform Commission, the Ministry of Environmental Protection, and the Energy Administration jointly issued the "Action Plan for Energy Conservation, Emission Reduction, Upgrading, and Transformation of Coal-fired Power (2014-2020)" (Fa Gai Energy [2014] No. 2093) [2], which proposes to implement comprehensive energy-saving transformation. Due to plant conditions, steam turbine flow section transformation, boiler flue gas waste heat recovery and utilization, motor frequency conversion are adopted Mature and applicable energy-saving transformation technologies such as heating transformation will focus on implementing comprehensive and systematic energy-saving transformation for 300000 kW and 600000 kW subcritical and supercritical units. After the transformation, the power supply coal consumption will strive to reach the advanced level of similar units.

This article takes the 300MW subcritical unit of a certain power plant as an example to analyze the problems that exist in the unit. By carrying out flow modification on the unit to reduce throttling losses during operation and improve the operational efficiency of the unit, three flow modification schemes for the unit's steam turbine were proposed. The technical parameters, energy-saving effects, and economic benefits of each scheme before and after the modification were compared and analyzed, and recommended schemes were given.

2. Overview of Unit Operation

2.1. Specification for Unit Steam Turbines

The steam turbine generator unit of a certain power plant is a subcritical, once reheated, and directly air-cooled unit with basic load and peak shaving capacity. Currently, the unit operates mostly at a load of 50% to 75%. The specific specification parameters are shown in Table 1.

Table 1. Specific Specification Parameters of Unit Steam Turbine

Turbine type	Subcritical, primary intermediate reheat, dual cylinder dual exhaust, direct air-cooled condensing steam type
Turbine model	NZK300-16.67/538/538
Rated power	300MW
Maximum continuous power	320MW
Rated steam pressure in front of the main steam valve	16.7MPa
Rated steam temperature in front of the main steam valve	538℃
Steam flow rate in front of the main steam valve	938.146t/h
Rated steam temperature in front of the Zhonglian valve	538℃
Rated back pressure	13.5kPa
Speed	3000r/min
Summer full hair back pressure	32kPa
Rated working condition feedwater temperature	271.8℃
Regenerative stage	3 high pressure heaters, 3 low pressure heaters, and 1 deaerator

2.2. Current Operation Status of the Unit

The corrected heat rate of the 300MW steam turbine is much higher than the design value, which is 367.61 kJ/kWh higher than the design value (8126.50 kJ/kWh).

According to the test results, the heat rate of the steam turbine after Unit A repair has decreased, but there is still a significant difference from the original design heat rate, resulting in a decrease in overall efficiency and economic efficiency.

Table 2. Comparison Data of Cylinder Efficiency for 300MW Test Condition Units

Number	Name	Original design value (%)	Test Value (%)	Deviation (%)
1	Efficiency of HP cylinder	84.87	79.42	-5.45
2	Efficiency of IP cylinder	91.88	89.03	-2.85
3	Efficiency of LP cylinder	92.51	85.80	-6.71

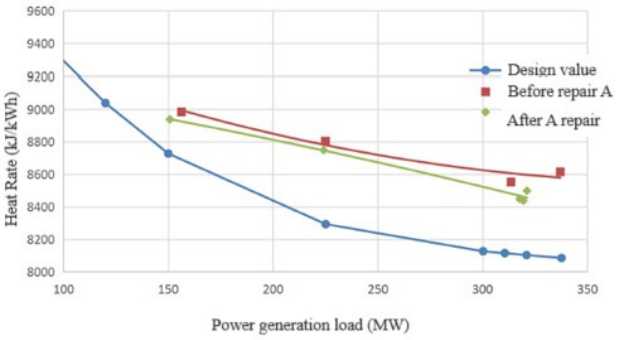


Figure 1. Relationship Curve between Unit Test Heat Rate and Power Generation Load

Based on multiple performance tests and on-site investigations, relevant factors affecting the economic operation of the unit have been identified. If the flow clearance of the steam turbine exceeds the standard seriously, the structure is relatively backward, and the internal efficiency decreases significantly; Under reduced back pressure operation, the heat consumption still cannot reach the original design value. Through analysis, the relevant factors that affect economic operation mentioned above cannot be solved through major repairs. It is necessary to replace corresponding components or improve design in order to achieve the optimal operating state of the entire unit.

Except for the slightly better efficiency of the intermediate pressure cylinder after unit A repair, the efficiency of the other cylinders of the unit's steam turbine is low and below the average level. The low efficiency of each cylinder of the steam turbine is the main reason for the high heat rate. It is necessary to retrofit the steam turbine with three cylinder flow passage based on the actual problems encountered in the operation of the power plant's steam turbine.

3. Improvement Plan for Flow Passage of Unit Steam Turbine

3.1. Basic Principles of Flow Transformation

For the overall renovation project of the flow passage part of the power plant unit, advanced AIBT flow passage technology is adopted on the basis of the original unit framework for steam turbine core replacement, increasing the number of flow passage stages and improving flow efficiency. At the same time, structural optimization is carried out on the high-temperature and high-pressure components of the original unit to solve the safety hazards and adverse factors for efficient operation in the old unit, improve the operational stability and reliability of the original unit, and increase the unit output, Significantly reduce the heat consumption of the unit, improve economic benefits, and strive to achieve energy-saving and emission reduction effects as much as possible.

The basic principles for the flow transformation of the power plant are as follows:

(1) On the premise of not affecting the post renovation effect, try to use the original equipment as much as possible to reduce the renovation workload.

(2) During the transformation of the turbine body and flow passage, the existing main auxiliary systems related to the turbine remain unchanged.

(3) During the modification of the turbine body and flow passage, the position of each pipeline interface, the connection method and position between the turbine and the generator, and the existing turbine foundation should be kept unchanged.

(4) During the modification of the turbine body and flow passage, the low-pressure outer cylinder should be kept unchanged.

(5) The bearing seats of the steam turbine remain unchanged.

3.2. Improvement Plan for Flow Passage of High and Medium Pressure Cylinders

The flow passage of the high and medium pressure cylinder is designed using advanced AIBT flow passage technology, as shown in the following figure, effectively improving the efficiency of the medium pressure cylinder. The advanced AIBT flow technology has been widely applied in the design of high-power new and old units of Shanghai Electric, as well as in the latest combined cycle steam turbines. These units reflect the characteristics of high efficiency and stability in the measured performance indicators of the products designed with AIBT flow technology, with rich application performance and mature and reliable technology. After the transformation, both the dynamic and static blades of the high and medium pressure flow passage parts adopt the overall shroud curved and twisted blade shape, and are all single piece milled and fully machined, with characteristics such as good strength, low dynamic stress, and good high-temperature creep resistance.

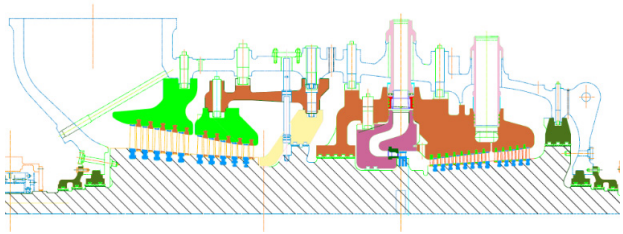


Figure 2. Schematic diagram of the transformation plan for high and medium pressure cylinders

3.3. Low Pressure Cylinder Flow Modification Plan

The low-pressure cylinder flow modification will still use AIBT technology for flow design, and the final stage blades will be selected based on the local climate conditions of the power plant and the exhaust, power, and back pressure requirements of the power plant. The LP inner cylinder adopts a new type of slant support structure: tapered steam inlet passage, special extraction chamber, variable cross-section extraction port optimization to reduce the pressure loss in the bladeless area, reasonable layout of scaffolding to facilitate maintenance and transportation, etc., which makes the whole

inner cylinder structure more reasonable.

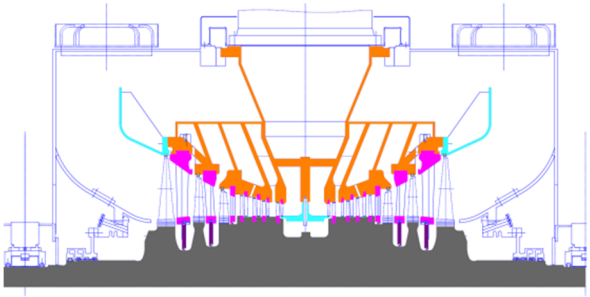


Figure 3. Schematic diagram of low-pressure cylinder renovation plan

3.4. Overview of Unit Steam Turbine Flow Path Transformation Plan

The steam turbine flow modification and parameter optimization can be divided into three schemes, namely:

Scheme 1: Conduct flow transformation on the high, medium, and low pressure cylinders of the steam turbine to maintain the parameters of the main steam and reheat steam unchanged.

Scheme 2: Conduct flow transformation on the high, medium, and low pressure cylinders of the steam turbine, maintain the main steam parameters unchanged, and increase the reheat steam temperature to 566 ℃.

Scheme 3: Conduct flow transformation on the high, medium, and low pressure cylinders of the steam turbine, maintain the main steam pressure unchanged, and increase the temperature of both the main steam and reheat steam to 566 ℃.

For Scheme 2 and Scheme 3, the scope of renovation includes not only the internal parts of the steam turbine, but also the material upgrade of the high and medium pressure outer cylinder and steam distribution mechanism of the steam turbine.

4. Comparison and Analysis of Flow Path Transformation Schemes for Unit Steam Turbines

4.1. Comparative Analysis of Technical Parameters

According to the load statistics and power generation situation of the power plant, the ratio of 50%, 75%, and 100% load rates of the unit is 2:2:1, and the weighted average heat consumption and power supply coal consumption are calculated based on this ratio.

4.1.1. Situation before Renovation

The heat consumption and power coal consumption of Unit A after repair are as follows:

Table 3. Heat consumption and power coal consumption of Unit A after repair

Name	300MW	225MW	150MW
Heat rate of steam turbine generator unit (kJ/kwh)	8494.11	8749.22	8937.84
Standard coal consumption rate for power supply of the unit (g/kwh)	352.87	356.37	364.82
Weighted average heat rate (kJ/kwh)	8773.65		

4.1.2. Situation after Renovation

The main parameters of the three retrofit schemes for steam turbines are as follows:

Table 4. Main Parameters of Scheme 1 Renovation Plan

Name	300MW	225MW	150MW
Main steam pressure/temperature (MPa (a) /℃)	16.67/538	16.35/538	11.14/538
Main steam flow rate (kg/h)	932058	679559	453363
High temperature reheat steam pressure/temperature (MPa (a) /℃)	3.26/538	2.43/538	1.67/538
High temperature reheat steam flow rate (kg/h)	780679	578758	394463
Efficiency of HP cylinder (%)	85.7	80.9	80.7
Efficiency of IP cylinder (%)	92.8	92.8	92.4
Efficiency of LP cylinder (%)	90.2	90.9	89.6
Steam turbine heat consumption (kJ/kWh)	8186.6	8359.9	8776
Standard coal consumption rate for power supply of the unit (g/kwh)	340.09	340.51	358.22
Weighted average heat rate (kJ/kWh)	8491.68		
Weighted average coal consumption for power supply (g/kwh)	347.51		

Table 5. Main Parameters of Scheme 2 Transformation Plan

Name	300MW	225MW	150MW
Main steam pressure/temperature (MPa (a) /℃)	16.67/541	16.67/541	11.40/541
Main steam flow rate (kg/h)	910576	668758	445839
High temperature reheat steam pressure/temperature (MPa (a) /℃)	3.38/566	2.53/566	1.74/566
High temperature reheat steam flow rate (kg/h)	762894	569672	388291
Efficiency of HP cylinder (%)	85.6	80.8	80.6
Efficiency of IP cylinder (%)	92.8	92.8	92.4
Efficiency of LP cylinder (%)	90.4	91.0	89.7
Steam turbine heat consumption (kJ/kWh)	8136.6	8314.7	8733.5
Standard coal consumption rate for power supply of the unit (g/kwh)	338.01	338.67	356.48
Weighted average heat rate (kJ/kWh)	8446.6		
Weighted average coal consumption for power supply (g/kwh)	345.66		

Table 6. Main Parameters of Scheme 3 Transformation Plan

Name	300MW	225MW	150MW
Main steam pressure/temperature (MPa (a) /℃)	16.67/566	16.67/566	11.81/566
Main steam flow rate (kg/h)	893121	652287	436479
High temperature reheat steam pressure/temperature (MPa (a) /℃)	3.348/566	2.492/566	1.716/566
High temperature reheat steam flow rate (kg/h)	752506	558275	381266
Efficiency of HP cylinder (%)	85.6	80.7	80.6
Efficiency of IP cylinder (%)	92.8	92.8	92.3
Efficiency of LP cylinder (%)	90.5	91.0	89.7
Steam turbine heat consumption (kJ/kWh)	8075.4	8249.9	8664.6
Standard coal consumption rate for power supply of the unit (g/kwh)	335.47	336.03	353.67
Weighted average heat rate (kJ/kWh)	8380.88		
Weighted average coal consumption for power supply (g/kwh)	342.97		

4.1.3. Comparison of Energy-saving Effects before and after Renovation

The energy-saving effects of the three schemes after renovation compared to before renovation are as follows:

Table 7. Comparison of energy-saving effects of three schemes

Number	Name	Before renovation	Scheme 1	Scheme 2	Scheme 3
1	Weighted average coal consumption for power supply (g/kWh)	359.06	347.51	345.66	342.97
2	Reduce standard coal consumption for power supply (g/kWh)	Reference	11.55	13.40	16.09
3	Annual utilization hours (h)	4500			
4	Annual coal savings (10000 tons)	Reference	1.56	1.81	2.17
5	CO_2 Emission reduction (10000 tons /a)	Reference	3.83	4.45	5.34
6	SO_2 Emission reduction(t/a)	Reference	5.76	6.69	8.03
7	NO_2 Emission reduction (t/a)	Reference	8.26	9.58	11.50
8	Smoke and dust emission reduction (t/a)	Reference	1.71	1.99	2.39

When the power generation is the same, the three schemes for steam turbine flow modification under the existing power generation utilization hours of the power plant have saved power supply standard coal consumption of 11.55g/kWh, 13.40g/kWh, and 16.09g/kWh, respectively. The power supply coal consumption of the three schemes under high load rate of the unit reaches the average level of the active unit.

4.2. Comparative Analysis of Economic Benefits

After considering the economic benefits of the above renovations, the investment and income comparison of the three schemes for unit flow renovation are shown in the table below:

Table 8. Comparison of Investment and Income of Three Schemes

Number	Name	Scheme 1	Scheme 2	Scheme 3
1	Renovation investment (10000 yuan)	10279	20600	26400
2	Annual coal saving income (including tax, 10000 yuan)	1423.74	1633.05	1938.00
3	Annual emission reduction income (10000 yuan)	254.23	291.61	346.06
4	Total income (10000 yuan)	1677.97	1924.66	2284.06
5	Investment payback period (years)	7.12	12.98	14.56

Note: 1. The data in the table is calculated based on the annual utilization hours of 4500 hours. 2. The price of CO2 emission rights is 30 yuan/ton, the price of NO2 and SO2 emission rights is 1263.16 yuan/ton, and the price of smoke and dust emission rights is 550.46 yuan/t. 3. The standard coal price including tax is 420 yuan/ton.

5. Conclusion

The three schemes for steam turbine flow transformation in the power plant have saved power supply standard coal consumption of 12.56g/kWh, 14.41g/kWh, and 17.10g/kWh compared to before the transformation. The energy-saving and emission reduction effect of Scheme 1 is lower than that of Scheme 2 and Scheme 3, but Scheme 1 has a shorter investment recovery period, a smaller transformation scope, a smaller engineering quantity, simple design and construction, and a shorter transformation cycle. Due to the unchanged parameters of the main steam and reheat steam in this scheme, the impact on the heating surface of the boiler is relatively small.

Although Plan 2 and Plan 3 have good coal saving and emission reduction effects, they involve the renovation of reheat pipelines, bypass valves, and boilers, with a large scope of renovation, complex design and construction, a long renovation cycle, and a long investment recovery period. Due to the changes in the main steam parameters and reheat steam parameters of this plan, which will have a significant impact on the heating surface of the boiler, there has not been any implementation performance of this type of parameter upgrade plan for the boiler.

Based on comprehensive analysis, it is recommended that Option 1 is the preferred option, which involves retrofitting the high, medium, and low-pressure cylinders of the steam turbine to maintain the parameters of the main steam and reheat steam unchanged.

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