Performance Test of a 660MW Thermal Power Unit Steam Turbine Based on the Background of “Double Carbon”

Ziwei Zhong[1,*], Lingkai Zhu[1], Wei Zheng[1], Zhiqiang Gong [1], Panfeng Shang [1], Junshan Guo[1], Jun Liu [1], Yanpeng Zhang[1]

State Grid Shandong Electric Power Research Institute, Jinan, China

Abstract. Under the background of "carbon peaking and carbon neutralization", China proposes a new power system with new energy as the main body. Due to the strong randomness, volatility and anti peak shaving characteristics of new energy power generation, in order to promote the consumption of new energy and ensure the power supply, coal power generation units will assume the dual tasks of deep peak shaving and power supply guarantee in the future, gradually changing from electric power supply to regulated power supply. In order to accurately grasp the thermal performance of the steam turbine after the flow passage transformation of the unit, the thermal performance assessment test of the steam turbine of the unit was carried out. Through thermal test, determine the heat rate and efficiency of high, medium and low pressure cylinders of the unit, and provide reference for future economic operation of the unit.

key word: Deep peak shaving; Thermal performance assessment test.

1. Introduction

The steam turbine of a 660MW power plant is N660-24.2/566/566 supercritical, one intermediate reheat, single shaft, three cylinder and four exhaust condensing steam turbine produced by Shanghai Turbine Works. In order to further increase capacity and reduce consumption, the power plant entrusted Shanghai Electric Group Co., Ltd. to comprehensively upgrade the flow passage of high, medium and low pressure cylinders of the steam turbine. In order to accurately grasp the thermal performance of the steam turbine after the flow passage transformation of the unit, the thermal performance assessment test of the steam turbine of the unit was carried out. Through thermal test, determine the heat rate and efficiency of high, medium and low pressure cylinders of the unit, and provide reference for future economic operation of the unit.

Table 1. Basic parameters of test unit

Rated power	660MW
Steam turbine inlet pressure	24.2MPa
Steam turbine inlet temperature	566℃
Temperature before reheat steam inlet valve	566℃
Rated back pressure	4.2kPa
Back pressure in summer	6.5kPa
Speed	3000r/min
Driving mode of feed water pump	Small machine drive
Direction of rotation	The turbine is clockwise when looking at the generator end
Heat consumption under rated working condition	7545.1kJ/kW.h(1802.1kcal/kW.h)

---

[*] Corresponding author: dkyzhongziwei@163.com

2. Performance test process of steam turbine

2.1 Test conditions

The thermal performance test of steam turbine is conducted under seven effective working conditions, namely T01 (3VWO1), T02 (3VWO2), T03 (TRL), T04 (TMCR), T05 (2VWO1), T06 (50% THA) and T07 (2VWO2). See the following table for specific test conditions and test time.

Table 2. Test conditions and test schedule

No.	Test condition	Test date	Test time
T01	3VWO1	July 23, 2022	11:30-13:30
T02	3VOW2	July 23, 2022	14:00-16:00
T03	TRL	July 24, 2022	10:15-12:15
T04	TMCR	July 24, 2022	14:35-15:35
T05	2VWO1	July 24, 2022	21:30-23:30
T06	50%THA	July 24, 2022	1:30-2:30
T07	2VWO2	July 24, 2022	18:00-20:00
T01	3VWO1	July 23, 2022	11:30-13:30
T02	3VOW2	July 23, 2022	14:00-16:00
T03	TRL	July 24, 2022	10:15-12:15
T04	TMCR	July 24, 2022	14:35-15:35

2.2 Test standards and benchmarks

The test points are arranged according to the requirements of ASME PTC 6-2004 test procedure.

2.2.1 Main measuring points include generator power, main steam pressure and temperature, high discharge pressure and temperature, reheat pressure and temperature, feedwater temperature, intermediate discharge pressure and temperature, exhaust pressure of low pressure cylinder, extraction pressure and temperature of each section, steam inlet pressure and temperature of each heater, inlet and outlet temperature and drainage temperature of each heater, main condensate flow, steam inlet flow of small turbine, etc.

2.2.2 Multiple measuring points shall be arranged for important measuring points that have a great impact on the test results, such as main steam, high pressure exhaust, reheat, intermediate exhaust, feedwater, deaerator outlet water temperature, low pressure cylinder exhaust steam pressure, etc.

2.2.3. Main flow measurement: high precision and low precision recommended by the calibrated ASME PTC6 standard β The main condensate flow is measured by the pressure tapping flow nozzle at the throat. The nozzle is installed on the condensate pipe between the outlet of No. 5 low pressure heater and deaerator, and the pressure is taken by two groups of pressure tapping holes.

2.2.4 Auxiliary flow measurement: the inlet steam flow of the small turbine is measured with a standard throttling device; The inlet and return flow of seal water of feed pump shall be measured by ultrasonic flowmeter; The desuperheating water flow of reheater takes the DCS historical data.

2.2.5 Measurement of exhaust pressure of low pressure cylinder: the exhaust pressure of low pressure cylinder is measured by cage probe, which is arranged at the throat of the interface between condenser and exhaust cylinder. One cage probe is uniformly arranged at each exhaust port, totaling 4 probes.

2.3.6. Measurement of open leakage in the system: the amount of open leakage that cannot be isolated from the thermal system shall be measured by the tester with a measuring cylinder and stopwatch using the volumetric method.

According to the requirements of each test condition, the operating personnel shall adjust the operating parameters of the unit and keep them stable. The deviation and fluctuation shall meet the requirements of the test procedures, and the regenerative system shall be put into normal operation. Adjust the valve position of high-pressure control valve according to the requirements of test conditions (load), and keep the valve position unchanged during the test.The unit operates under unit system and is isolated strictly according to the system isolation list. Make up water to the system, adjust the water level of deaerator water tank and hot well to a higher value, keep the water level of each heater normal and stable, and stop making up water. During the test, the water level of deaerator water tank and hot well changes steadily to avoid violent fluctuations.After the unit operates stably for more than half an hour and the test instrument and data acquisition system are confirmed to work normally, start the test recording. The test duration under each working condition is 1-2 hours. The data acquisition cycle of the data acquisition device is once every 30 seconds; Data in DCS shall be recorded once every 1 second; Each parameter recorded manually, with a reading cycle of 5 minutes

2.3 Test data processing and calculation

The main condensate flow is calculated by the discharge coefficient obtained through calibration, and the flow calculation formula is:

$$q_c = \frac{\pi}{4} C \cdot \varepsilon \cdot d^2 \sqrt{\frac{2\Delta p \cdot \rho_{f1}}{1-\beta^4}}$$

kg/s

In the formula:

C — Nozzle discharge coefficient;

ε — Expansion coefficient of fluid;

https://doi.org/10.1051/e3sconf/202337502016

d —— Nozzle throat diameter under actual operation state, m;

Δp —— Nozzle differential pressure, Pa;

ρ_{f1} —— Density of measured medium, kg/m^3;

β —— The ratio of nozzle throat diameter to pipe inner diameter under actual operation condition.

Determination of steam leakage flow of shaft seal and valve stem:

The air leakage of high pressure valve rod and the air leakage of shaft seal before and after high and medium pressure are all taken as design values.Distribution of unknown leakage of the system: the unknown leakage of the system shall not exceed 0.5% of the main steam flow, and the unknown leakage shall be divided according to 50% of the steam turbine and 50% of the boiler.

$$\Delta G = G_{da} + G_{hw} - G_{ml}$$

In the formula:

ΔG —— Unknown leakage of the system, t/h;

G_{da} —— Equivalent flow of deaerator water tank water level change (water level drop is positive), t/h;

G_{hw} —— Equivalent flow of condenser hot well water level change (water level drop is positive), t/h;

G_{ml} —— Open leakage of the system, t/h.

The calculation formula of feedwater flow is as follows：

$$G_{ffw} = G_{cw} + G_{da} + G_{HP3d} + G_{DAstm} + G_{mfs} - G_{rhs}$$

In the formula:

G_{ffw} —— Final feedwater flow, t/h;

G_{cw} —— Main condensate flow, t/h;

G_{HP3d} —— Drainage flow of 3 # high-pressure heater, t/h;

G_{DAstm} —— Deaerator steam inlet flow, t/h;

G_{mfs} —— Flow difference between inlet and return of sealing water of feed pump, t/h;

G_{rhs} —— Desuperheating water flow of reheater, t/h.

The calculation formula of main steam flow is as follows:

$$G_{ms} = G_{ffw} - \Delta G_b$$

In the formula：

G_{ms} —— Main steam flow, t/h;

ΔG_b —— Boiler side leakage, t/h.

The calculation formula of cold reheat steam flow is as follows:

$$G_{crh} = G_{ms} - G_{vlHP} - G_{glHP} - \sum_{i=1}^{2} G_{exi}$$

In the formula：

G_{crh} —— Cold reheat steam flow, t/h;

G_{vlHP} —— Total steam leakage of high-pressure valve rod, t/h;

G_{glHP} —— Total steam leakage from the front shaft seal to the intermediate pressure cylinder of the high pressure cylinder and the rear shaft seal of the high pressure cylinder, t/h;

G_{ex} —— Extraction flow, t/h.

The calculation formula of cold reheat steam flow is as follows:

$$G_{hrh} = G_{crh} + G_{rhs}$$

In the formula：

G_{hrh} —— Hot reheat steam flow, t/h.

The calculation formula of test heat rate is as follows:

$$HR = \frac{G_{ms} \times h_{ms} + G_{hrh} \times h_{hrh} - G_{ms} \times h_{ffw} - G_{crh} \times h_{crh} - G_{rhs} \times h_{rhs}}{P_g}$$

In the formula：

HR —— Test heat rate, kJ/(kW. h);

h —— Enthalpy corresponding to each flow, kJ/kg;

P_g —— Generator active power, MW;

3. Conclusion

The turbine output test conditions include TRL and TMCR. The main results are listed in the following table:

Table 3.Main results of unit output test conditions

parameter	unit	TRL	TMCR
Generator active power	MW	680.1870	694.2040
Pressure after regulating stage	MPa	18.0532	18.2058
Main steam pressure	MPa	24.3213	24.3236
Main steam temperature	℃	565.06	564.94
Enthalpy of main steam	kJ/kg	3391.79	3391.40
Main steam flow	t/h	1946.6843	1960.9472
Unknown leakage	t/h	7.8881	4.7068
Unknown leakage rate	%	0.41	0.24
Reheat pressure	MPa	4.2360	4.2704
Reheat temperature	℃	563.54	563.47
Reheat enthalpy	kJ/kg	3587.26	3586.78
Reheat flow	t/h	1695.4189	1708.3157
High discharge pressure	MPa	4.5895	4.6264
High discharge temperature	℃	319.79	320.57
High exhaust enthalpy	kJ/kg	2999.33	3000.41
Cold reheat flow	t/h	1642.9189	1653.2757
Intermediate discharge pressure	MPa	1.0068	1.0137
Intermediate discharge temperature	℃	348.93	348.63
Intermediate exhaust enthalpy	kJ/kg	3156.14	3155.36
Exhaust pressure of low pressure cylinder	kPa	7.2225	6.0435
Feedwater pressure	MPa	28.2007	28.2432
Feed water temperature	℃	280.38	281.05
Feedwater enthalpy	kJ/kg	1231.71	1234.99
Feedwater flow	t/h	1946.6843	1964.2828
Desuperheating water flow of reheater	t/h	52.5	55.04
Class II corrected electric power	MW	682.2337	706.7006

The test electric power of the unit turbine under TRL (nameplate output, design exhaust pressure 6.5kPa) condition is 680.1870 MW, and the electric power after Class II correction is 682.2337 MW, reaching the design value of 680 MW;

The test power of the unit turbine under TMCR (maximum continuous output) condition is 694.2040MW, and the power after Class II correction is 706.7006MW, reaching the design value of 699.9MW.

Acknowledgements

This work is supported by the science and technology project of Electric Power Research Institute of State Grid Shandong electric power company(ZY-2022-15), which studies Research on peak capacity improvement of thermal power unit based on electric heating coordination optimization under guaranteed supply demand.

References

1. Liu Xiaohong，Zhu Litong，Yang Shoumin，etc. Study on calculation method of overall performance test of thermal power plant [J].Thermal Power Generation，2006，35 (3)：3-10.
2. Wang Xuedong，Wang Xuetong，Yang Jianzhu，etc. Energy saving transformation and thermal performance assessment test of flow passage of Unit 2 in Laiwu Power Plant [J].Shandong Electric Power Technology, 1998 (4)：4-12.
3. Ji Ansen.Results and Analysis of Thermal Performance Test of Unit #12 in Wuhu Power Plant before Overhaul [J]. Anhui Electric Power Technical Information，2000，000 (002)：7-8.
4. Weng Sicheng.Thermal performance test of SAIC 300MW steam turbine (Wangting Power Plant Unit 12) [J]. Shanghai Turbine，1983 (01)：5-20.
5. Song Guoliang，Chang Hao，Wang Baoyu，etc. Study on Numerical Calculation Method of Uncertainty of Thermal Performance Test Results of Thermal Power Plants [C].Promoting the Revolution of Energy Production and Consumption - Proceedings of the 10th Yangtze River Delta Energy Forum two thousand and thirteen.
6. Wang Jizhou Study on thermal system mechanism model and off design operating characteristics of coal-fired power generation units [D].Huazhong University of Science and Technology，2015.