Analysis of high energy consumption of 1000MW ultra supercritical unit

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Abstract. A 1000MW ultra supercritical unit heat consumption rate was higher than design value 324.81 kJ/kW h, in this paper, by comparing the conventional test and assessment test, the result of the analysis of conventional test data at the same time, found out the factors that affect the unit heat consumption, low efficiency of unit mainly include cylinder and putting-in-service proactively reheat steam consumption reduction of warm water, small machine increase, feed water by-pass leakage, system other internal leakage, etc., application of equivalent enthalpy drop method, calculated the influence of the influence factors on the heat consumption of value.

1. Introduction
N1013-28/600/620 ultra-supercritical, primary intermediate reheat, single-axis four-cylinder four-exhaust, condensing steam turbine was produced by Shanghai steam turbine factory. The design value of turbine performance parameters and the test results in June 2017 were shown in Tab. 1. According to the test results, the overall performance of the machine was slightly better than the design value.

Table 1. Comparison of assessment test and design value.

| Name                        | Assessment test | Design value THA |
|-----------------------------|-----------------|------------------|
| Heat rate(kJ/kW.h)          | 7224.05         | 7231             |
| HP cylinder efficiency(%)   | 89.71           | 89.89            |
| IP cylinder efficiency(%)   | 92.47           | 92.96            |
| LP cylinder efficiency(%)   | 88.84           | 89.66            |
| Boiler efficiency (%)        | 95.13           | 94.59            |
| Power consumption rate (%)  | 4.22            | 4.59             |
| Gross coal consumption rate (%) | 261.73        | 263.47           |
| Power supply coal consumption rate (%) | 273.19       | 276.15           |

In April 2019, in order to grasp the actual performance of the unit after 2 years of operation, the power plant commissioned the test unit to conduct a conventional thermal performance test on the unit #1, testing the thermal consumption rate, high pressure cylinder efficiency, medium pressure cylinder efficiency, coal consumption of the unit's power generation, coal consumption of the unit's power supply and other performance indexes. The test was carried out in accordance with GB/T 8117.2-2008 "steam turbine thermal performance acceptance test regulations" [1]. Pure condensate performance tests were carried out in five working conditions, namely 1000MW, 850MW, 700MW, 550MW and 400MW. The test results showed that, under the 1000MW working condition, the high pressure
cylinder efficiency of the unit is 85.97%, the medium pressure cylinder efficiency was 91.43%, and the heat consumption rate of the unit after class ii correction was 7555.81kJ/ kW.h. It could be seen that the heat consumption rate of the unit is 324.81 kJ/ kW.h higher than the design value.

By comparing the test data of #1 machine, the two tests of this conventional test, and the difference between the test value and the design value of the thermodynamic system, the equivalent enthalpy drop theory [2] was applied to analyze the thermodynamic system, found out the reasons for the high heat consumption rate of the unit, and provided ideas for the overhaul and operation optimization of the unit.

2. HP and IP cylinder efficiency

In February 2017, before the production test, the test unit conducted a routine performance test on the #1 machine. In order to analyze the cylinder efficiency changes since the production, this paper compared the high and high cylinder efficiency changes under the three THA working conditions tests. The data are shown in Tab. 2.

Compared with the THA condition in February 2017, the THA condition of this time has basically the same opening of the high switch, and the efficiency of the high-pressure cylinder is reduced by about 1.21 percentage points. Two years after the two tests, the reduction of the efficiency of the high-pressure cylinder is mainly affected by the aging of the unit. Compared with the THA condition tested in June 2017, the efficiency of the high-pressure cylinder was reduced by about 3.74 percentage points. Comparative data can be seen that the high tone had a greater influence on the opening of high pressure cylinder efficiency, the high tone as the assessment test opening, throttling loss of small, high efficiency, high pressure cylinder and the actual operation, consider to meet the requirements of the power grid a frequency modulation, the opening of the high tone is must have a certain allowance [3], so it needs to sacrifice certain economy.

| Name                        | 201904 THA | 201702 THA | 201706 THA | Design value THA |
|-----------------------------|-----------|-----------|-----------|-----------------|
| High adjustable door opening(%) | 42.56     | 41.99     | 89.97     | 100             |
| Main steam pressure (MPa)   | 27.75     | 27.21     | 26.72     | 26.37           |
| Main steam temperature (℃)  | 591.45    | 592.41    | 595.92    | 600             |
| HP cylinder efficiency(%)   | 85.97     | 87.18     | 89.71     | 89.89           |
| IP cylinder efficiency(%)   | 91.43     | 92.90     | 92.47     | 92.96           |

The analysis of the influence of the reduction of high and medium pressure cylinder efficiency on the heat consumption rate of the unit is generally based on the calculation method given in ASME PTC6S REPORT 1970 simplified method of steam turbine routine test [4]. In this paper, the influence of 1% change of high-pressure cylinder efficiency on the heat consumption rate of the unit is calculated according to the above method and unit design parameters respectively:

$$\Delta HR_{hp} = \left( \frac{W_{hp} \times \eta_m \times \eta_a - G_r \times H_{hp}}{3600 \times N_t \times HR} \right) \times 100\%$$  \hspace{1cm} (1)$$

Similarly, the influence of 1% change in the cylinder efficiency on the heat consumption rate of the unit is also calculated:

$$\Delta HR_{ip} = \left( \frac{W_{ip} \times \eta_m \times \eta_a}{3600 \times N_t} \right) \times 100\%$$  \hspace{1cm} (2)$$

Using formula (1) and formula (2), each change of 1 percentage point in the high-pressure cylinder efficiency of #1 machine will affect the heat consumption rate of 16.98kJ/ kW.h; Every 1 percentage point change in the medium pressure cylinder efficiency affects the heat consumption rate of 37.65kJ/ kW.h. In this THA condition, the efficiency of the high-pressure cylinder was 85.97%, 3.92 percentage points lower than the design value, which increased the heat consumption rate by about 66.41kJ/ kW.h and the coal consumption by about 2.53g/ kW.h. The efficiency of the medium
pressure cylinder was 91.43%, 1.53 percentage points lower than the design value, which increased the heat consumption rate by about 57.66kJ/kW.h and the coal consumption by about 2.19g/kW.h.

3. Reheat the lukewarm water
In the balance diagram of the steam turbine thermal system, the flow rate of reheat desuperheating water is 0. However, due to the overtemperature of reheater wall at the furnace side, a certain amount of accident desuperheating water needs to be invested to control the reheater wall temperature. The reheating of desuperheating water increases the heat absorption of the thermal system. At the same time, since the reheating desuperheating water is not heated by the reheating heater and the high-pressure cylinder does work, the circulation efficiency is lower than the mainstream working medium, and the heat consumption rate and coal consumption rate of the unit increase. Based on the equivalent heat drop theory, the heat consumption rate of the unit is about 1.87‰ when the additional water reduction accounts for 1% of the main steam flow rate.

In this THA condition, the heat loss rate of the unit increased by about 37.8kJ/kW.h, and the coal loss increased by about 1.44g/kW.h. It is suggested that the power plant should strengthen the adjustment of boiler side combustion, adopt the tail flue gas baffle to adjust the reheat temperature, and try not to spray water with reheater in normal operation, so as to improve the operation economy.

4. Small engine steam consumption
The machine is equipped with a small 100% capacity engine and a separate small engine condenser. Condensate is recycled to the large engine heat well. The small engine coaxially drives the front pump and feed pump. Affected by various factors, the actual operating efficiency of small engine is generally lower than the design value, which inevitably leads to the small engine steam consumption is higher than the design value. The increase of the small engine steam consumption reduces the power capacity of the main engine and increases the energy consumption of the unit. Generally, when analyzing the influence of small engine steam consumption on energy consumption, it is usually just to compare the numerical difference between test steam consumption and design steam consumption, and then to calculate the influence value of energy consumption by applying the theory of equivalent heat drop. This calculation method is one-sided. It does not consider the influence of the deviation between the design value and the inlet and outlet parameters of the small engine on the steam consumption. In this paper, according to the test feed pump set enthalpy rise, test small machine parameters, test feed flow, test reheat desaturation water flow, small machine design efficiency, to calculate the modified small machine design steam flow, and then compare with the small machine test steam flow. The calculation formula of the design steam inlet flow of the small engine is as follows:

$$G_c = \frac{G_p \times \Delta H_p + G_j \times \Delta H_j}{\eta \times \Delta H_{to}}$$

Table 3 shows the comparison between the test parameters and design values of the machine. In this THA condition, the efficiency of the small machine is 76.7%, and the design steam inlet flow of the modified small machine is 141.28t/h. The steam consumption of the test small machine is 13.45t/h higher than the modified design value. Then, the equivalent heat drop theory is applied to calculate that the heat consumption rate of the unit increases about 23.66kJ/kW.h, and the coal consumption increases about 0.90g/kW.h.
5. Water main bypass leakage
The water supply system of machine #1 is equipped with 3 high adding heaters and 1 external type evaporator. The water supply system of machine #1 is divided into two ways, one is external type evaporator, the other is external type evaporator bypass. Three steam extraction advanced external steam cooler, and then into #3 high add; The main water supply bypass is from the #3 high inlet to the external evaporator outlet.

Table 4. Comparison of final feed temperature and outlet temperature of #1 HP heater.

| Name                  | 201904 THA | 201702 THA | Design value |
|-----------------------|------------|------------|--------------|
| Economizer inlet temperature(℃) | 295.13     | 298.28     | 299.3        |
| Outlet temperature of #1 HP heater(℃) | 296.67     | 293.72     | 295.4        |

In order to eliminate the influence of measurement point and measurement error on the value, temperature values in Tab. 4 are all taken from the same DCS measurement point data of two tests. It can be seen that in February 2017, THA and the design value, the water supply temperature is about 4℃ higher than that of #1 plus effluent temperature, which is mainly affected by the heating of external evaporator. In this THA condition, the feed water temperature is 1.54℃ lower than that of #1 high water outlet, indicating serious leakage in the large water supply bypass. There is no flow meter in the large water supply bypass, so the heat balance calculation can only be carried out for the section of water supply pipeline (including external steam cooler) from the high-adding outlet of #1 to the inlet of the economizer. On the whole, the heat entering this area is #1 high adding water, 3 pumping to steam inlet of the evaporator, and leakage in the large water supply bypass. The heat leaving this area is the inlet water supply of the economizer, and #3 high adding steam. Through heat balance and iterative calculation, the leakage flow in the large water supply bypass can be calculated. Table 5 shows the calculation results of the leakage in the large water supply bypass under five test conditions:

Table 5. Water main bypass leakage in each condition.

| Name     | 1000MW | 850MW | 700MW | 550MW | 400MW |
|----------|--------|-------|-------|-------|-------|
| Water main bypass leakage(t/h) | 130.01 | 102.78 | 83.83 | 63.97 | 46.76 |

This part of the large water supply bypass does not flow through the high heating, which reduces the heat recovery steam extraction and the heat recovery degree, and also causes the water supply temperature to be about 4℃ lower than the design value, which reduces the thermal economy of the unit. Taking THA as an example, the heat consumption rate of the unit increased by about 10.95kJ/kW.h, and the coal consumption increased by about 0.42g/kW.h.

6. Other internal leakage
The unknown leakage rate of the system under various test conditions is lower than the limit stipulated in GB/T 8117.2-2008 "steam turbine thermal performance acceptance test regulations", indicating that the high energy consumption of the unit has nothing to do with external leakage. The cooling degree of condenser under various test conditions is all negative, while the design value is ≤0.5℃, indicating that the condenser has internal heat leakage, which enters into the condenser without work, reducing the economic efficiency of the unit. Before the test, it was found in the thermal system that there were several large internal leaks in machine #1: the temperature behind the valves on side A and side B of the low side was 180℃, the pneumatic steam trap on the right side of the main steam pipe was 200℃, and the high-pressure steam inlet pipe of the small machine was often open to trap water.

Table 6. Condenser supercooling in each condition.

| Name     | 1000MW | 850MW | 700MW | 550MW | 400MW |
|----------|--------|-------|-------|-------|-------|
| Condenser supercooling(℃) | -0.4991 | -0.5485 | -0.3770 | -0.2432 | -0.0458 |
7. **Overall analysis of high unit energy consumption**

Table 7. Causes of high energy consumption in THA condition.

| Name                      | Affects the heat loss rate(kJ/kW.h) | Affect the coal consumption(g/kW.h) |
|---------------------------|------------------------------------|-------------------------------------|
| HP cylinder efficiency    | 66.41                              | 2.53                                |
| IP cylinder efficiency    | 57.66                              | 2.19                                |
| Reheat the lukewarm water | 37.8                               | 1.44                                |
| Small engine steam consumption | 23.66                           | 0.90                                |
| Water supply bypass       | 10.95                              | 0.42                                |
| Total                     | 196.48                             | 7.48                                |

In THA condition, the heat consumption rate of the unit after modification is about 324.81kJ/ kw.h higher than the design value. Through the analysis of the thermodynamic system of the unit in the previous sections, the reasons affecting the energy consumption of the unit have been found as follows: low HP and IP cylinder efficiency, reheat desaturation of warm water, increase of steam consumption of small machine, leakage in large water supply bypass, etc. The total influence heat consumption rate is 196.48kJ/ kw.h. The heat consumption rate of the remaining 128.33kJ/ kw.h is limited by the conventional thermal performance test of the steam turbine, and cannot be analyzed quantitatively specifically, including: 1. Accuracy of feed water flow measurement; 2. Low pressure cylinder efficiency reduction caused by aging of low pressure cylinder; 3. The steam leakage of shaft seals increases; 4. Leakage in the system.

8. **Conclusion**

In this paper, by comparing the previous test data and analysis for thermal system, find out the reason of higher energy consumption of the unit, there are mainly high school low pressure efficiency and putting-in-service proactively reheat steam consumption of warm water reduction, small machine, feed water by-pass leakage, etc, and through the calculation of the equivalent enthalpy drop and so on, gives the influence on the unit energy consumption values, for power plant unit overhaul and operation optimization provides a train of thought.

**References**

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