Experimental study on back pressure correction coefficient of ultra-supercritical steam turbine

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Abstract. The micro increase output test is a reliable and effective way to obtain the back pressure correction curve of steam turbines. The test results are not only applicable to daily energy-saving analysis of steam turbines, but also instructive in the optimal operation of circulating water system. With a 660MW ultra-supercritical steam turbine unit as the research object, the back pressure correction curves of the unit THA condition, 75%THA condition and 50%THA condition were obtained by the micro increase output test. During the test, the flow of condensate was kept unchanged to avoid the influence of the changes of the low-pressure regenerative extraction flow on the test results.

1. Introduction
In power plant operation, the back pressure of the steam turbine usually has a large range of changes due to many factors such as unit load, circulating water flow, cooling water temperature, condenser cleanliness, vacuum tightness, the working characteristic of condenser and pumping equipment and so on, which significantly affects the output and economy of the unit[1]. The Power-back pressure Characteristics of the turbine refers to the variation characteristics of power when the back pressure changes[2]. Since most manufacturers only provide back pressure correction curves under some typical conditions and even only provide back pressure correction curves under rated condition, it is more difficult to meet the needs of field applications[3]. Moreover, the system, equipment, load and all parameters are different from the design condition, and changed year by year in the actual operation. When these curves can’t accurately reflect the turbine power changes, checking the original design correction curve will produce a larger error [4].

2. Unit overview
The steam turbine is N660-25/600/600 ultra-supercritical, one intermediate reheat, single axis, combined HP-IP cylinder, three cylinders, four exhaust ports, double back pressure condensing steam turbine.

| Table 1. Design Data of the Unit |
|---------------------------------|
| Item                            | THA  | 75%THA  |
|---------------------------------|------|---------|
| Unit load(MW)                   | 660  | 495     |
| Main steam pressure(MPa)        | 25.00| 20.70   |
| Main steam temperature(℃)      | 600.0| 600.0   |
| Reheat steam pressure(MPa)      | 4.42 | 3.30    |
Reheat steam temperature(℃)  600.0  600.0  
Seventh extraction steam pressure(MPa)  0.111  0.084  
Seventh extraction steam temperature(℃)  122.2  124.4  
Eighth extraction steam pressure(MPa)  0.049  0.038  
Eighth extraction steam temperature(℃)  81.0  74.8  
Exhaust flow(t.h⁻¹)  1035  805  
Back pressure(kPa)  5.54  5.54  
Condensate pump water temperature(℃)  35.0  35.0  
Feed pump turbine inlet flow(t.h⁻¹)  92.8  53.6  
Feed pump turbine exhaust pressure(kPa)  6.34  5.84  

3. Micro Increase Output Test
The conventional heat balance calculation method is currently more accurate method of calculating the thermal system variable conditions, which is usually used as the basis for comparison of other calculation methods. When the back pressure changes, the change of the electrical power of the steam turbine generator is calculated through the thermal balance of the steam turbine thermal system. However, during the calculation process, some necessary assumptions have been made, and there are also problems with the selection of empirical coefficients (of which the exhaust steam loss characteristics of the last stage blades has not been verified by the entity, and the variable condition calculations of the relevant moisture loss and the feed pump steam turbine are also slightly insufficient). Although it can ensure that the calculation error is in the range of the allowable range of the project, it also has certain limitations. In principle, both the theoretical calculation method and the manufacturer's correction curve need to be subject to field tests.

In theory, it is a reliable method to determine the influence of the initial-final parameters of steam turbines on output and economy by the test method, and the result is most suitable for the actual situation. In particular, the fluctuation range of vacuum is relatively large when the unit is running. The impact on the output and economy are the most significant. Calculating the back pressure correction curve with the theoretical method is sometimes difficult or not accurate, so the test method is commonly used in power plants to seek the power-back pressure Characteristics[5].

With a 660MW ultra-supercritical steam turbine unit as the research object, the back pressure correction curves of the unit THA condition, 75%THA condition and 50%THA condition were obtained by the micro increase output test.

4. Test Methods and Results Analysis
The purpose of turbine micro increase output test is to get the functional relationship between power and back pressure, by artificially varying the condenser vacuum and maintaining the inlet steam parameters and flow of the steam turbine unchanged.

4.1 Test Program and Measures
Due to the excellent vacuum system tightness of the test unit, the vacuum pump was shut down to change the condenser vacuum by means of simulation vacuum tightness test. In order to expand the scope of the back pressure changes, the test was carried out in winter and two circulating pumps were started.

Specific test measures: The valve control mode of the DEH system is set to the manual mode, maintaining the valve position of the high pressure control valve unchanged, and the primary frequency modulation function of the unit is removed; In the process of test, the boiler feed-water flow and the main/reheat steam parameters should be maintained stability as much as possible. The boiler reheat flue gas damper should be adjusted to reduce the investment and fluctuation of reheat steam desuperheated water. If the coal quality changes, the main steam temperature will fluctuate abnormally, then, the amount of coal should be adjusted by appropriate adjustment. Before starting the test, the
pumping air connection valve between the high and low pressure condensers should be opened. The chemical personnel should be informed to stop sampling, the boiler personnel should be informed not to carry on the blow ash, the steam turbine personnel should be informed to stop supplying steam to the outside, and not to supply water to the condenser, and to prevent other operations to affect the normal operation of the thermal system.

It should be emphasized that in order to avoid that the condensate flow has large fluctuations which in turn causes a change in the low-pressure regenerative extraction flow, both the pump speed and deaerator water level control valve are set to manual position to keep the condensate flow stable during the test.

After all the relevant pre-test preparations are met, all vacuum pumps will be stopped until the parameters of main steam pressure, main / re-heat temperature, generator power and condensate flow are stable for half an hour, so that the condenser vacuum will slowly decline. Generally, the test time may last 1 hour for units with excellent vacuum tightness. During this period, the hot well water temperature of the condenser can fully track the increase of back pressure and slowly rise. The inlet steam flow of feed pump turbine also increases slowly with the increase of back pressure.

4.2 Trend Chart of Micro Increase Output Test
Several typical conditions test were arranged according to the unit load from high to low. The trend chart of micro increase output test of THA condition, 75% THA condition and 50% THA condition are shown in Figure 1, Figure 2 and Figure 3.

![Figure 1. Trend Chart of Micro Increase Output Test of THA Condition](image1)

![Figure 2. Trend Chart of Micro Increase Output Test of 75% THA Condition](image2)
4.3 Back Pressure Correction Curve

Because the back pressure usually changes above the ultimate vacuum which is restricted by the lowest unit load and the lowest cooling tower outlet water temperature, the back pressure characteristics are basically linear law. After correcting of the main parameters and condensate flow, the back pressure correction coefficient equations were fitted out from field test data under each condition.

Back pressure correction coefficient equation under THA condition:

\[ \kappa_p = -0.8351 \times p + 6.6266 \]  

(1)

Back pressure correction coefficient equation under 75%THA condition:

\[ \kappa_p = -1.0856 \times p + 6.0141 \]  

(2)

Back pressure correction coefficient equation under 50%THA condition:

\[ \kappa_p = -1.3964 \times p + 7.7359 \]  

(3)

In these formulas: \( \kappa_p \) is the back pressure correction factor under different conditions; \( p \) is the condenser back pressure.

Figure 4 shows the back pressure correction curve after correcting of the main parameters and condensate flow under each condition.

Figure 3. Trend Chart of Micro Increase Output Test of 50% THA Condition

Figure 4. Back Pressure Correction Curves
4.4 Comparison between Test Results and Conventional Heat Balance Calculation and Manufacturer's Correction Curves

Table 1 below shows the influence of the back pressure to the unit power in the range of 5.54 kPa to 12 kPa (average value in this range).

| Item                                    | THA  | 75%THA | 50%THA |
|-----------------------------------------|------|--------|--------|
| Test results (kW)                       | 5512 | 5374   | 4608   |
| Conventional heat balance calculation  | 6437 | 5862   | 4685   |
| results (kW)                            |      |        |        |
| Manufacturer's correction curve (kW)    | 6488 | 6113   | /      |

The table 1 shows that the numerical values of micro increase output of the test results are lower than those of conventional heat balance calculation results and manufacturer's correction curve, and the higher the load is, the larger the difference is. It is obvious that the back pressure characteristics obtained by the field test results are more instructive to guide the field operation.

5. Conclusion

Although the conventional heat balance calculation method can ensure that the calculation error is in the range of the allowable range of the project, it also has certain limitations. In principle, both the theoretical calculation method and the manufacturer's correction curve need to be subject to field tests. The purpose of turbine micro increase output test is to get the functional relationship between power and back pressure, by artificially varying the condenser vacuum and maintaining the inlet steam parameters and flow of the steam turbine unchanged. It is a reliable and effective way to obtain the back pressure correction curve of steam turbines. The test results are not only applicable to daily energy-saving analysis of steam turbines, but also instructive in the optimal operation of circulating water system.

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