Performance analysis of small steam turbine in high back pressure heating unit

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Abstract. In view of the change of the operation mode of the small steam turbine of the high back pressure modified unit, the performance evaluation formula of the small steam turbine and the feed water pump is given. Through the performance test, the performance indexes of the small steam turbine and the feed water pump set are obtained, and the detailed data analysis is carried out. It is found that the modified small steam turbine and the feed water pump set do not meet the design requirements. The analysis of the test results, found the reasons for the performance is not up to the standard, and gave the next step.

Keywords: High back pressurer; small steam turbine; feed water pump; performance indicators.

1. Introduction

High back pressure steam exhaust in the circulating water heating is the condenser pressure increase [1], namely lower condenser vacuum degree, improve the cooling water temperature, change the condenser to heater heating system of the network, directly used for heat supply network of circulating water and cooling water, make full use of condensing steam turbine exhaust steam of the latent heat of vaporization heat of circulating water, the cold source loss reduce to zero, thus improve the cycle thermal efficiency of the unit [2-4].

In the initial high back pressure heating retrofitting, only the low pressure flow order is changed, so that the operating back pressure of the unit is higher than the normal back pressure under pure condensing condition [5], the cold source loss during heating is zero, the retrofitting cost is low, and there is no need to shut down and switch between heating and non-heating periods. However, this one-time transformation of the low-pressure rotor and separator to improve the operating back pressure of the unit leads to poor economic performance in non-heating period, especially in summer, which has a great impact on the load and energy consumption of the unit. In recent years, the implementation of 135 mw steam turbine transformation of low pressure cylinder "double back pressure double rotor" interchange technology, the introduction of high back pressure in the heating period of low pressure rotor, the heating period use the low pressure rotor [6], the two are interchangeable, improve the ability of the unit heating, the increase in the heating area, both the heating period unit efficiency and unit efficiency does not affect the heating season.

After the high back pressure modification of the main engine, the small steam turbine also needs to be modified accordingly. Summer operation, drive steam turbine steam intake for the main engine four-stage extraction steam. When the main engine runs in summer, there is no heating, the extraction parameters of the four stages are unchanged, and the power and speed of the pump are unchanged. To drive the steam turbine to meet the high back pressure conditions in winter, the blades become shorter and the exhaust steam passage area is reduced. In summer, the exhaust steam pressure rises to 0.008MPa. Running in winter, the steam inlet of the drive turbine is the cold end steam of the reheater. When the main engine runs in winter, the power of the feed pump increases greatly, while the back pressure of the driving turbine increases. The steam inlet of the turbine needs to adopt the cold end steam of the reheater. Due to the strength, it is necessary to throttle and reduce the pressure with the regulating valve before entering the turbine.

Main modification contents of small steam turbine:

1) Designed and processed new rotor assembly and replaced blade materials;

2) Designed and calculated the steam inlet parameters, and transformed the nozzle ring of the steam chamber;

3) Design and process new guide vane ring assembly and replace blade material;

4) Redesign, provide steam turbine new characteristic curve, tuning speed control system.

2. Performance test and calculation method

When the unit runs with high and low back pressure double rotors, the operating conditions of the steam driven feed pump set vary greatly [7]. The economic indexes and performance of the steam driven feed pump set under the two operating conditions are studied by the performance test. The performance of steam driven feed pump set is measured under guaranteed and variable working conditions, and the efficiency change of steam driven feed pump set is determined under different loads. The steam feed pump test and the steam turbine test are carried out simultaneously. Under the high back pressure heating condition, 230MW and 180MW tests are carried out. Under normal back pressure conditions, 320MW, 270MW and 210MW conditions were tested.

Feed pump head:

$$H = \frac{p_2 - p_1}{\rho g} + (z_2 - z_1) + \frac{v_2^2 - v_1^2}{2g} \tag{1}$$

Where, p_1 is inlet pressure of pump set, Pa; p_2 is outlet pressure of pump group, Pa; v_1 is pump inlet flow rate, m/s; v_2 is pump outlet flow rate, m/s; z_2 and z_1 are outlet and inlet pressure transmitter elevation, m; ρ is average density of pump inlet and outlet water, kg/m3; g is acceleration due to gravity, 9.81 m/s^2.

Feed pump useful power:

$$P = \rho \times g \times H \times Q \tag{2}$$

Where, Q is outlet flow, m^3/s.

Conversion of feed pump performance, conversion of pump performance parameters under measured speed to performance parameters under rated speed from the following equation.

$$Q_0 = \frac{n_0}{n} \times Q \tag{3}$$

$$H_0 = \left(\frac{n_0}{n}\right)^2 \times H \tag{4}$$

$$P_{a0} = \left(\frac{n_0}{n}\right)^3 \times P_a \tag{5}$$

Where, Q_0 is flow rate at rated speed, kg/h; H_0 is head at rated speed, m; P_{a0} is shaft power at rated speed, kW; n_0 is rated speed, r/min; n is test speed, r/min.

3. Results analysis

The test results of steam driven feed pump set are shown in Table 1 under the conditions of 230MW and 180MW high back pressure and 320MW, 270MW and 210MW normal back pressure.

Table 1. Calculation results of performance test

Parameter	Unit	High back pressure of 230MW	High back pressure of 180MW	Normal back pressure of 320MW	Normal back pressure of 270MW	Normal back pressure of 210MW
Feed pump inlet pressure	MPa	1.8716	1.7662	1.7884	1.6704	1.6463
Feed pump outlet pressure	MPa	18.5383	17.3562	19.4288	18.5964	17.7305
Feed pump inlet flow rate	kg/h	439949.1	330559.9	524406.8	437514.2	325683.2
Feed pump outlet flow rate	kg/h	436852.7	330559.9	520249.6	435735.4	333683.2
Inlet flow rate of feed pump	m/s	1.847	1.372	2.193	1.809	1.339
Outlet flow rate of feed pump	m/s	4.084	3.059	4.841	4.013	3.057
Feed pump head	m	1876.87	1736.553	1977.98	1877.53	1774.24
Feed pump total useful power	kW	2230.89	1559.324	2833.405	2246.202	1607.645
Small engine premier wants power	kW	6469.47	4749.26	4448.34	3530.32	2661.6
Pump group efficiency	%	34.483	32.833	63.696	63.626	60.401
Output power of small steam turbine	kW	2778.82	2041.14	3414.24	2740.71	2042.93
Feed pump efficiency	%	80.282	76.395	82.988	81.957	78.693
Small steam turbine efficiency	%	42.953	42.978	76.753	77.633	76.756
Design speed of feed pump	r/min	5815	5815	5815	5815	5815
Measured steam pump speed	r/min	4748.36	4383.64	4978.02	4687.56	4368.05
Pump outlet flow after correction	kg/h	534984.4	438495.4	607721.8	540537.4	444218.3
Corrected pump outlet head	m	2814.79	3055.75	2699.03	2889.3	3144.39
Corrected feed pump shaft power	kW	5103.62	4764.5	5442.2	5232.05	4819.92

3.1 Influence on performance index of small steam turbine

The variable working conditions and different steam sources affect the performance of small steam turbines. It can be seen from the test results in Table 1 that under the high back pressure 230MW and 180MW conditions and the normal back pressure 320MW, 270MW and 210MW conditions, the feed pump efficiency is 80.282%, 76.395%, 82.988%, 81.957% and 78.693%, respectively. When the main steam flow is similar, there is little difference in the feed pump efficiency between the high back pressure test condition and the normal back pressure test condition [8].

Under the conditions of high back pressure 230MW and 180MW and normal back pressure 320MW, 270MW and 210MW, the driving efficiency of the steam turbine is 42.593%, 42.978%, 76.753%, 77.633% and 76.756%, respectively. Since the driving turbine efficiency cannot be modified by back pressure, the efficiency of driving turbine under high back pressure condition is much lower than that under low back pressure condition. Under normal back pressure and high back pressure conditions, the turbine efficiency obtained in the test does not reach the designed efficiency of 80.1% in summer and 77.2% in winter.

Under the conditions of high back pressure 230MW, 180MW and normal back pressure 320MW, 270MW, 210MW, the efficiency of steam feed pump set is 34.483%, 32.833%, 63.696%, 63.626%, 60.401% respectively.

Due to the high back pressure steam feed water pump set of winter running, sharing a set of inlet steam flow orifice, and because of admission adjustable valve, cannot contain the four extraction, only into the steam flow rate and the average energy distribution, feed water pump and so on steam to drive a turbine is analyzed separately, the normal working condition of high back pressure and back pressure test results and conclusion on the contrary, But the calculated test results of the whole feed pump set are relatively accurate and can be used to analyze the test results.

The retrofit of steam driven feed pump set can meet the requirements of safe operation under high back pressure heating conditions. However, under normal back pressure and high back pressure conditions, the efficiency of feed pump set is low, which needs to be optimized in field operation and design in the same project.

3.2 Impact on host performance indicators

After the high back pressure heating modification of the unit, 4VWO condition, 4VWO repeated condition, maximum pure coagulation output condition, 200MW condition and 180MW condition were carried out. The average high pressure cylinder efficiency is 81.304%, medium pressure cylinder efficiency is 88.51%, low pressure cylinder efficiency is 93.6%, and the corrected heat consumption rate is 3830.78 kJ/kW.h. The efficiency of high pressure cylinder, medium pressure cylinder and low pressure cylinder is 81.346%, 87.232% and 93.538%, respectively, and the corrected heat consumption rate is 3888.2 kJ/kW.h. The efficiency of high pressure cylinder, medium pressure cylinder and low pressure cylinder is 82.385%, 91.15% and 94.131% respectively. As a high back pressure modified unit, the efficiency of the modified low pressure cylinder is slightly lower than the design value.

Under the high backpressure pure coagulation condition, the test heat consumption rate is between 3756.4kJ/kW.h -- 3913.8kJ/kW.h, and the corrected heat consumption rate is between 3724.4kJ/kW.h -- 3888.2kJ/kW.h. The thermal efficiency of the unit is between 92.6% and 96.66%, which fluctuates little and irregularly with the working condition. This is mainly because the unit is in the state of high back pressure heating, the high temperature circulating water bears a large amount of external heating, and the operating parameters of the cold end of the unit are greatly affected by the heat load [9].

When the circulating water flow of the heat network reaches 11200t/h, the back pressure of the unit is 54.9kPa, close to the design back pressure of 54kPa, and the high back pressure pure coagulation output of the unit reaches 230.4MW and the design output reaches 229.7MW.

Under the extraction condition of 246.2t/h, the steam intake flow of the unit is 1005.06t/h, the power generation output is 223.47MW, the backpressure of the condenser is 40.6kpa, and the low-pressure cylinder efficiency is 90.87%. Under the design condition of similar main steam flow, the designed steam intake volume of the unit is 970t/h, the power generation output is 238.93MW, the heating steam extraction volume is 190t/h, the backpressure of the condenser is 54kPa, and the low-pressure cylinder efficiency is 93.906%.

Unit with heating extraction conditions, by heating extraction and high back pressure circulating water heating at the same time, with the increase of amount of extraction, low pressure cylinder flow reduce, condensing unit through pressure drop, high back pressure heating load decreases, and at the same time under the condition of the same main steam flow rate, unit power output is lower, in order to ensure the unit and economic benefits for the factory, The heating operation mode of the unit and the whole plant should be optimized. The high back pressure heating of the unit should be used first, and then the heating extraction steam with gradually increasing pressure should be used in turn.

4. Conclusion

Under the conditions of high back pressure 230MW, 180MW and normal back pressure 320MW, 270MW, 210MW, the feed pump efficiency is 80.282%, 76.395%, 82.988%, 81.957%, 78.693%. The driving turbine efficiency was 42.593%, 42.978%, 76.753%, 77.633%, 76.756%, respectively. The efficiency of steam feed pump group is 34.483%, 32.833%, 63.696%, 63.626%, 60.401% respectively. Under normal back pressure and high back pressure conditions, the turbine efficiency obtained in the test does not reach the designed efficiency of 80.1% in summer and 77.2% in winter.

When the circulating water flow of the heat network reaches 11476t/h, the back pressure of the turbine is 54.95kPa, and the output of the unit reaches 230.4MW. When the steam intake of the unit is 1025t/h, the heating capacity is 460.2MW. Under high back pressure heating condition, the average heat consumption rate is 3706.6kJ/kWh, and the thermal efficiency is above 96%. The boiler efficiency is calculated as 91%, and the plant power consumption rate is calculated as 8%. The coal consumption of the unit for power generation and power supply is 139g/kWh and 151g/kWh, respectively. The heat consumption rate and coal consumption rate after high back pressure modification are much lower than those before modification (6534kJ/kWh and 269g/kWh, respectively). In one heating cycle, the standard coal quantity is saved 64,600 tons and the heating area is increased by 4 million square meters. It has replaced a large number of small boilers in urban areas. According to the coal consumption of 65kg/GJ for heating of small boilers and 42kg/GJ for central heating of large units, about 28,300 tons of standard coal can be saved every year. The above two measures can comprehensively save 92,900 tons of standard coal, reduce sulfur dioxide emissions by 2,933 tons and nitrogen oxide emissions by 883 tons in the heating season, resulting in significant environmental and social benefits.

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