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Analysis on the influence of cylinder efficiency on coal consumption of an ultra-supercritical double- reheat 1000 MW steam turbine unit

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Abstract. Taking an ultra-supercritical double-reheat 1000 MW steam turbine as an example, the influence rule of the ultra-high pressure cylinder, high pressure cylinder, intermediate pressure cylinder and low pressure cylinder on coal consumption of steam turbine under THA, 75%THA, 50%THA and 40%THA is analyzed. According to the data of cylinder efficiency on the heat consumption rate of steam turbine, combined with the design of the efficiency of the boiler and plant electricity rate, it is worth to work out the influence rule of cylinder efficiency on the power generation coal consumption and power supply coal consumption under THA condition. The conclusion shows that the influence of cylinder efficiency on coal consumption is basically linear. The efficiency of low pressure cylinder is the most sensitive, the efficiency of intermediate pressure cylinder is second, the efficiency of high pressure cylinder and ultra-high pressure cylinder has little effect on coal consumption. The conclusion can provide technical reference for energy-conservation diagnosis and management on the ultra-supercritical double-reheat 1000 MW steam turbine.

1. Introduction

Large steam turbines are designed with multi-cylinder structure. For conventional reheat units, there should be high pressure cylinder, medium pressure cylinder and low pressure cylinder. The efficiency of each cylinder refers to the ratio of the actual enthalpy drop of steam in the cylinder to the ideal enthalpy drop. With different load and operation regulation modes of the unit, the efficiency of the high-pressure cylinder changes greatly [1], while that of the medium-pressure cylinder changes little, and that of the low-pressure cylinder also changes to some extent [2]. With the improvement of steam parameters and material properties, double-reheat has become an important development direction of supercritical power generation technology [3]. At present, There are 58 double-reheat units have been put into operation worldwide, and 6 ultra-supercritical double-reheat units have been put into operation in China, both the steam parameters and the unit efficiency have reached the world advanced level [4]. Compared with the conventional reheat unit, the most significant feature of the double-reheat unit in terms of steam turbine flow technology is the addition of ultra-high pressure cylinder with higher pressure levels. This ultra-high pressure cylinder module designed based on the overall structure of small enthalpy drop, multiple series, reaction formula and cylinder shape is a continuation of the successful technology of the conventional reheat unit, not a breakthrough of essence [5].

At present, there are few literatures on the influence of the cylinder efficiency of double-reheat unit on coal consumption, which brings some troubles to the energy conservation management of power generation enterprises. Therefore, it is very important to accurately and quantitatively evaluate the influence of each cylinder efficiency on the coal consumption of the steam turbine on the energy-saving diagnosis and energy-saving management of the double-reheat unit.

2. The design parameters of an ultra- supercritical double-reheat 1000 MW steam turbine unit

In this paper, the ultra- supercritical double-reheat 1000 MW steam turbine unit produced by Shanghai electric co., LTD is taken as the research object. The steam turbine is designed with ultra-high pressure cylinder, high pressure cylinder, medium pressure cylinder and low pressure cylinder. The main steam first passes through the ultra-high pressure cylinder to do work, and its exhaust steam enters the high-pressure cylinder after being reheated. After double-reheated, the steam goes to the middle pressure cylinder and the low-pressure cylinder for further work. The pressure drop of reheat system is 6%, and that of double-reheat system is 10%. The unit is equipped with a 10-stage heat recovery system, in which the pressure loss of the first, second, third and fourth segments is 2.9%, and the remaining segments are 4.7%, the designed exhaust pressure is 4.8 kPa. The design parameters under THA condition are shown in table 1. The end difference of each heater in the thermal system is shown in table 2.

Table 1. Design parameters of double-reheat 1000 MW steam turbine under THA condition.

Content	unit	data	Content	unit	data
Main steam P	MPa	30.000	The second stage extraction P	MPa	6.096
Main steam T	ºC	600.0	The second stage extraction T	ºC	537.2
Main steam F	kg/s	711.937	The third stage extraction P	MPa	3.384
Ultra-high pressure cylinder exhaust steam P	MPa	10.618	The third stage extraction T	ºC	443.5
Ultra-high pressure cylinder exhaust steam T	ºC	426.2	The 4th stage extraction P	MPa	1.788
Reheat steam P	MPa	9.980	The 4th stage extraction T	ºC	536.2
Reheat steam T	ºC	620.0	The 5th stage extraction P	MPa	1.073
Reheat steam F	kg/s	633.514	The 5th stage extraction T	ºC	456.1
High pressure cylinder exhaust steam P	MPa	3.384	The 6th stage extraction P	MPa	0.744
High pressure cylinder exhaust steam T	ºC	443.3	The 6th stage extraction T	ºC	402.6
The double-reheat steam P	MPa	3.046	The 7th stage extraction P	MPa	0.405
The double-reheat steam T	ºC	620.0	The 7th stage extraction T	ºC	320.8
The double-reheat steam F	kg/s	545.969	The 8th stage extraction P	MPa	0.128
Medium pressure	MPa	0.397	The 8th stage	ºC	198.2

Content	unit	data	Content	unit	data
cylinder exhaust steam P			extraction T		
Medium pressure cylinder exhaust steam T	°C	321.3	The 9th stage extraction P	MPa	0.059
Condenser vacuum	kPa	4.8	The 9th stage extraction T	°C	122.2
The 1st stage extraction P	MPa	10.618	The 10th stage extraction P	MPa	0.022
The 1st stage extraction T	°C	426.2	The 10th stage extraction x	/	x=0.987

Table 2. Design value of end difference of heaters in thermal system under THA condition.

Heater number	1#	2#	3#	4#	6#	7#	8#	9#	10#
Upper end difference/°C	-1.7	0.0	0.0	0.0	2.8	2.8	2.8	2.8	2.8
Upper end difference/°C	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6

3. The influence of cylinder efficiency on heat consumption rate of steam turbine

According to the calculation model of constant power and variable operating conditions of the steam turbine, the influence rule of cylinder efficiency on thermal consumption rate of the steam turbine under THA, 75%THA, 50%THA and 40%THA is respectively calculated, as shown in table 3.

According to table 3, for every 1% reduction in the efficiency of the ultra-high pressure cylinder, the heat consumption rate increases by 6.85 kJ/(kW·h) to 8.12kJ/(kW·h). Under the conditions of THA, 75%THA, 50%THA and 40%THA, the heat consumption rate gradually increased. For example, if the efficiency of the ultra-high pressure cylinder decreases by 4 percentage points, the heat consumption rate of the steam turbine increases by 27.40 kJ/(kW·h) under THA condition and 32.48 kJ/(kW·h) under 40%THA condition. For every one percentage point reduction in high pressure cylinder efficiency, the heat consumption rate increases by 7.16 kJ/(kW·h) to 8.22kJ/(kW·h). Under the conditions of THA, 75%THA, 50%THA and 40%THA, the heat consumption rate gradually increased. For example, the efficiency of high-pressure cylinder decreases by 4 percentage points, the heat consumption rate of steam turbine increases by 28.64 kJ/(kW·h) under THA condition, and 32.88 kJ/(kW·h) under 40%THA condition. The influence of high pressure cylinder efficiency and ultra – high pressure cylinder efficiency is close.

Table 3. The influence of cylinder efficiency on heat consumption rate of the double-reheat 1000 MW steam turbine unit.

content	unit	THA	75%THA	50%THA	40%THA
Ultra-high pressure cylinder efficiency reduced by 1%	kJ/(kW·h)	6.85	7.11	7.70	8.12
High pressure cylinder efficiency reduced by 1%	kJ/(kW·h)	7.16	7.33	7.82	8.22
Intermediate cylinder efficiency reduced by 1%	kJ/(kW·h)	16.66	16.73	17.40	17.96
Low pressure cylinder efficiency reduced by 1%	kJ/(kW·h)	19.83	20.35	20.69	20.71

For every 1 percentage point reduction in the intermediate pressure cylinder efficiency, the heat consumption rate increases by 16.66 kJ/(kW·h) to 17.96kJ/(kW·h). Under the conditions of THA, 75%THA, 50%THA and 40%THA, the heat consumption rate gradually increased. For example, if the efficiency of intermediate pressure cylinder decreases by 4 percentage points, the heat consumption rate of the steam turbine increases by 64.44 kJ/(kW·h) under THA condition, and increases by 69.44 kJ/(kW·h) under 40% of THA condition. The influence of the intermediate pressure cylinder efficiency is much higher than that of ultra-high pressure cylinder and high pressure cylinder, which is mainly because the work done by the intermediate pressure cylinder takes a large proportion in the total shaft power of the whole double-reheat 1000 MW steam turbine.

For every 1 percentage point reduction in low pressure cylinder efficiency, the heat consumption rate increases by 19.83 kJ/(kW·h) to 20.71kJ/(kW·h). Specifically, it is related to load. Under the conditions of THA, 75%THA, 50%THA and 40%THA, the heat consumption rate gradually increases. For example, the efficiency of low-pressure cylinder decreases by 4 percentage points, the heat consumption rate of the steam turbine increases by 79.32 kJ/(kW·h) under THA condition, increases by 82.76 kJ/(kW·h) under 50%THA condition, and increases by 82.84 kJ/(kW·h) under 40%THA condition. Compared with 50%THA and 40%THA, the difference in heat consumption rate was only 0.08 kJ/(kW·h). The influence of low pressure cylinder efficiency is the biggest in the whole double-reheat turbine, which is also because the power of low pressure cylinder is the largest proportion of the total shaft power of the turbine. This is consistent with the conventional reheat unit.

4. The influence of cylinder efficiency on power generation coal consumption and power supply coal consumption

According to the above influence rules of cylinder efficiency on heat consumption rate, take the design value of boiler efficiency as 94.65% and the design value of plant electricity rate as 3.97%. According to the calculation method of technical and economic indicators of thermal power plants given by DL/T 904-2015, the influence of cylinder efficiency change on the power generation coal consumption and power supply coal consumption of the unit under THA is calculated, as shown in figures 1 and 2.

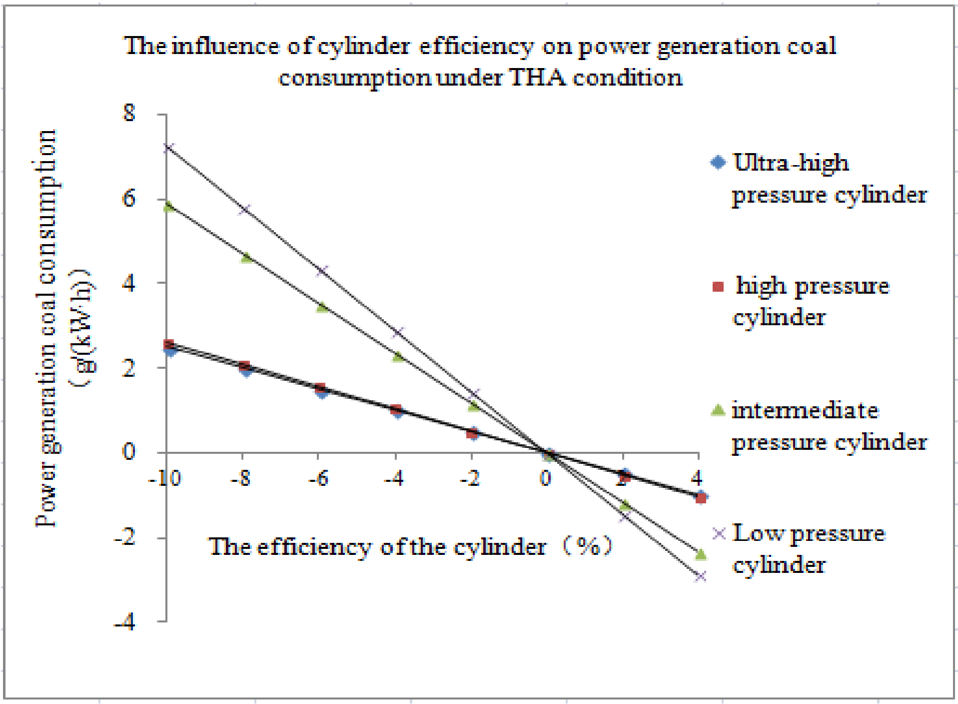

Figure 1. The influence of cylinder efficiency on power generation coal consumption.

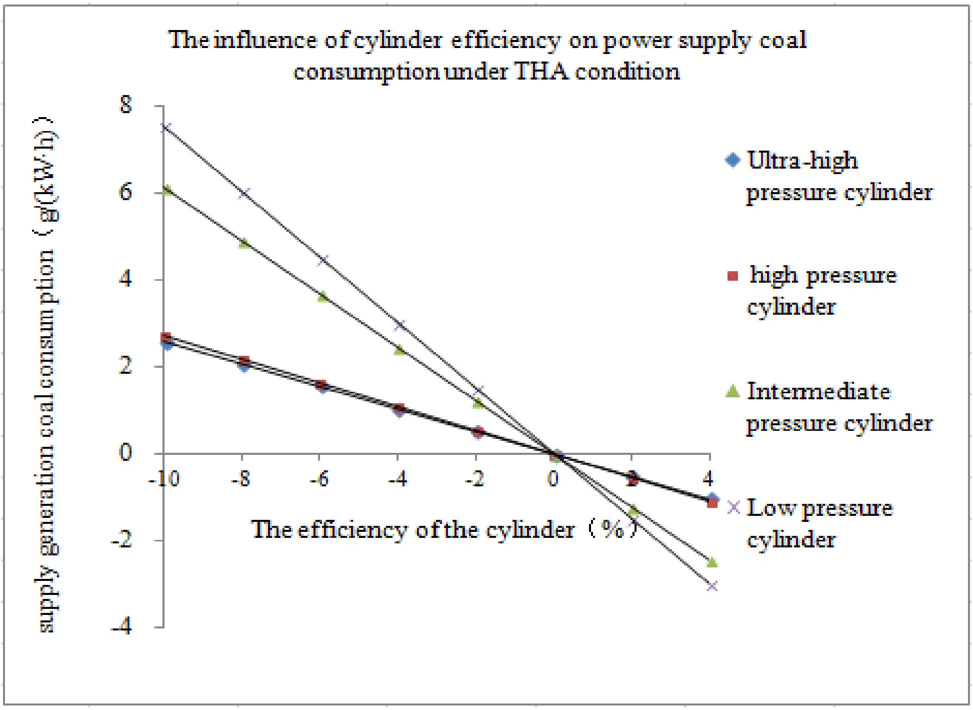

Figure 2. The influence of cylinder efficiency on power supply coal consumption.

According to the graph curve, the influence of ultra-high pressure cylinder efficiency and high pressure cylinder efficiency on the power generation/power supply coal consumption is almost the same. For every 2% reduction in efficiency, the power generation coal consumption increases by 0.50 g/(kW·h) and 0.52 g/(kW·h), respectively, and the power supply coal consumption increases by 0.52 g/(kW·h) and 0.54 g/(kW·h) respectively. The medium-pressure cylinder efficiency has a great impact on coal consumption. For every 2% reduction in efficiency, the power generation coal consumption increases by 1.17 g/(kW·h) and the power supply coal consumption increases by 1.22 g/(kW·h) respectively. In the whole flow passage of double-reheat turbine, the low pressure cylinder efficiency has the biggest influence on coal consumption. For every 2% reduction in low pressure cylinder efficiency, the power generation coal consumption increases by 1.44g/(kW·h), and the power supply coal consumption increases by 1.50 g/(kW·h). Due to the limitation of space, this paper only gives the influence rule of cylinder efficiency of double-reheat 1000MW steam turbine on coal consumption under THA condition, and the analysis method of other conditions is the same.

5. Conclusions

This paper takes supercritical secondary reheating 1000 MW steam turbine as the research object to study the influence law of cylinder efficiency on coal consumption. The influence of cylinder efficiency on heat consumption rate is obtained by using the calculation method of constant power and variable condition of steam turbine, according to the design value of boiler efficiency and plant electricity rate, the influence rule of cylinder efficiency on coal consumption is obtained. It is in order to provide technical reference for the energy-saving management and evaluation of double-reheat turbine, It is helpful for relevant employees to make energy-saving diagnosis and deeply excavate the energy-saving space of the unit. The main conclusions of this paper are as follows:

The efficiency of the ultra-high pressure cylinder decreases by 1 percentage point, and the heat consumption rate increases from 6.85 kJ/(kW·h) to 8.12kJ/(kW·h) under different load conditions. The efficiency of the high-pressure cylinder is close to that of the ultra-high pressure cylinder. Under the conditions of THA, 75%THA, 50%THA and 40%THA, the heat consumption rate gradually increased.

Because the power of the medium-pressure cylinder accounts for a large proportion of the total power of the turbine, the influence of the medium-pressure cylinder efficiency is much higher than that of the ultra-high pressure cylinder and the high-pressure cylinder. For every one percentage point reduction in the medium-pressure cylinder efficiency, the heat consumption rate increases from 16.66 kJ/(kW·h) to 17.96kJ/(kW·h) under different load conditions.

The efficiency of the low-pressure cylinder decreases by 1 percentage point, and the heat consumption rate increases to 19.83 kJ/(kW·h) to 20.71kJ/(kW·h) under different load conditions. Its influence is the biggest in the whole double-reheat turbine, which has the common characteristics with the conventional reheat turbine. Therefore, in the actual operation of the unit should focus on the operation of the low pressure cylinder.

The conclusions of this paper can be applied to the daily energy-saving management of ultra-supercritical double-reheat 1000 MW steam turbine. The low-pressure cylinder has the biggest influence on the energy consumption of this kind of turbine. The decrease of low-pressure cylinder efficiency by 1 percentage point affects the power supply coal consumption by 0.75 g/(kW·h). With the price of standard coal at 750 yuan/ton and the annual utilization hours of the unit at 4500, 3,375 tons of fuel can be saved and 2.53 million yuan of fuel cost can be saved every year.

The influence of cylinder efficiency of double-reheat 1000MW steam turbine on power generation/power supply coal consumption is consistent with the trend of thermal consumption. Through the influence of cylinder efficiency on the heat consumption rate of steam turbine, combined with the design value of boiler efficiency and plant electricity rate, the influence rules of each cylinder efficiency of steam turbine on the power generation/power supply coal consumption can be obtained.

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