Research on 1000MW double reheat ultra-supercritical six-cylinder six-exhaust steam-turbine generator set

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Abstract. This paper introduces the application technology of a million-second reheat ultra-supercritical six cylinder six exhaust steam turbine, through the analysis of six cylinder six exhaust steam overall design scheme, to calculate the stability of the shafting , and compared with the five cylinder four exhaust schemes. The results show that , the design scheme of six cylinder six exhaust steam turbine is breakthrough in the stability of shafting , at the same time, optimize the exhaust parameters of the low-pressure cylinder , make the unit back pressure at 2.9 kPa. Through the comparison of two schemes, six cylinder six exhaust steam turbine scheme can save the standard coal consumption by about 2.28 g/kWh per year, save coal cost about 6.27 million. However, the initial investment increased by 55 million, and the investment cost can be recovered in 8.8 years, its has high investment value and social benefits.

Keywords: Ultra supercritical, The second reheat, Six cylinder six exhaust steam, Stability of shafting, Benefit analysis.

1 Introduction

At the end of 2016, the national installed capacity of power generation was 1.65 billion kilowatts, a year-on-year increase of 8.2%. The total installed capacity of renewable energy power is 600 million kilowatts, accounting for 36.4%. By the end of 2015, 82 million units had been put into operation in China, becoming one of the countries with the most million units in the world. At present, the domestic one million kilowatt units are mostly five-cylinder four-exhaust steam type. In order to pursue higher internal efficiency of the steam turbine, it is necessary to improve the inlet steam parameters and reduce the exhaust steam pressure. In the process of designing and manufacturing the steam turbine, the improvement of the initial parameters requires higher alloy steel materials, which is greatly restricted by development. Therefore, it is necessary to reduce the exhaust steam pressure. There are two ways to reduce the back pressure: one is to increase the height of the last stage blade, but due to the high speed of the steam turbine, it is difficult to increase the height of the last

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stage blade. The second is to increase the exhaust area of the condenser by increasing the number of low-pressure cylinders.

In this paper, the number of low-pressure cylinders is increased to achieve a six-cylinder six-row steam turbine unit, and its technical characteristics and technical indicators are analyzed.

2 Technical characteristics of six cylinders and six exhausts

2.1 Overall plan

The object of this study is a 1000MW ultra-supercritical secondary reheat six-cylinder six-exhaust steam unit with a design back pressure of 2.9kPa. The nameplate is: 31MPa/600℃ /620℃/620℃. The sequence of each cylinder of the steam turbine is a series arrangement of a high-pressure cylinder, an ultra-high-pressure cylinder, a medium-pressure cylinder and three low-pressure cylinders, as shown in Figure 1.

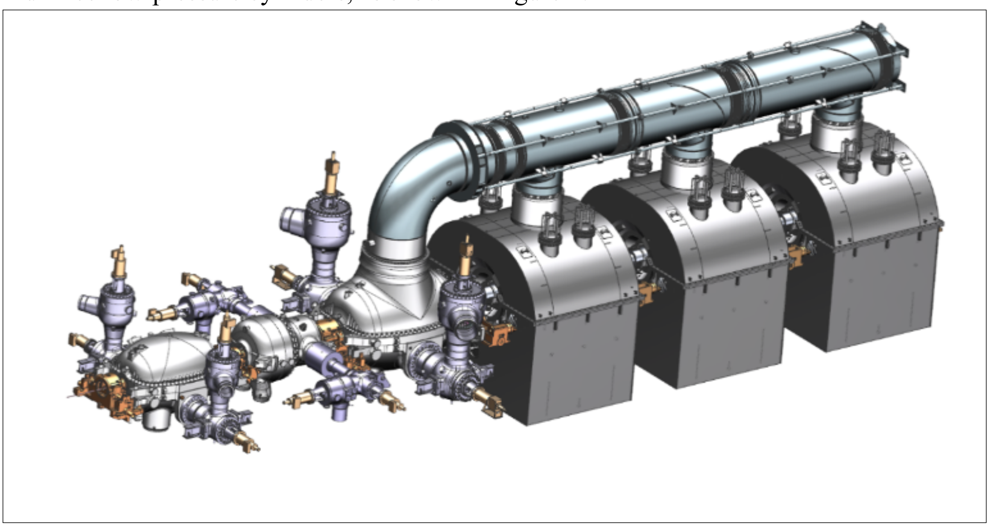

Fig. 1. 3D appearance of six cylinders and six exhausts.

2.2 Shafting stability characteristics

Compared with the five-cylinder, four-exhaust scheme, the six-cylinder, six-exhaust scheme has significantly longer shafting and corresponding changes in the expansion size of the shafting. The stability of the shafting is a technical problem worthy of attention. In order to solve the problems of shaft system stability and excessive differential expansion of the low-pressure cylinder, it is considered to adjust the cylinder arrangement sequence and the expansion dead point. In the five-cylinder four-exhaust scheme, the cylinders are arranged in sequence of an ultra-high-pressure cylinder, a high-pressure cylinder, a medium-pressure cylinder and two low-pressure cylinders, and the expansion dead point of the unit is located between the ultra-high-pressure cylinder and the high-pressure cylinder. However, in the six-cylinder six-exhaust scheme, the arrangement sequence of the cylinders is a high-pressure cylinder, an ultra-high-pressure cylinder, an intermediate-pressure cylinder and three low-pressure cylinders, and the expansion dead point is between the ultra-high-pressure cylinder and the intermediate-pressure cylinder. In addition, a radial thrust joint bearing is arranged on the No. 3 bearing pedestal. Therefore, the entire shaft system expands from the dead center to both ends. The cat claws of the high-pressure cylinder and the medium-pressure cylinder are also immobile at the No. 3 bearing seat. Therefore, the dynamic and static expansion directions of the entire unit are the same, which solves the problem of poor shaft expansion.

The shaft system of the steam turbine generator set is composed of eight rotors and ten bearing supports. Among them, the steam turbine part consists of a high pressure rotor (HP), an ultra-high pressure rotor (VHP), a dual-flow medium pressure rotor (IP) and three Composition of dual-flow low-pressure rotors (LP1, LP2, LP3); The generator part consists of a water-hydrogen-hydrogen generator (GEN) and a static exciter (EXC) rotor. The generator rotor is a double-support structure, and the excitation end of the exciter rotor is formed by a four-piece tilting pad bearing to form a three-support structure.

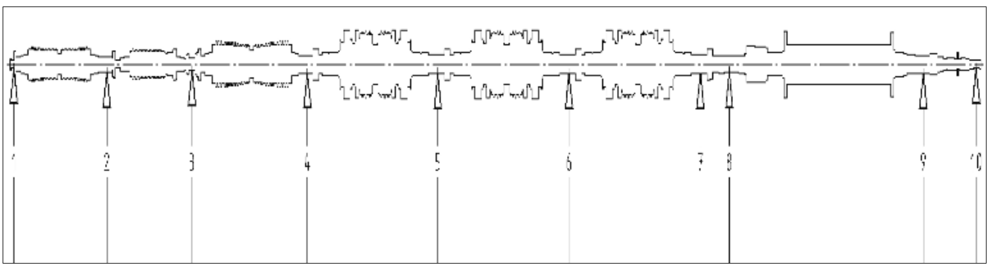

Fig. 2. The distribution diagram of the six-cylinder and six-exhaust steam support points and shafting.

By calculating the first and second-order damping critical speeds of the eight rotors, see the table below, which can meet the requirements of avoiding 10% of the rated speed (Siemens standard) and the national standard of 15%.

Table 1. The critical speed calculation table of the six-cylinder six-exhaust rotor.

Rotor	High pressure rotor	Ultra high pressure rotor	Medium pressure rotor	Low pressure rotor 1	Low pressure rotor 2	Low pressure rotor 3	Generator rotor	Exciter rotor
First-order critical speed(r/min)	1782	2202	1542	1296	1296	1290	732	3828
Second-order critical speed(r/min)	>4500	>4500	>4500	>4000	>4000	>4000	2172	>4500

In addition, through calculation, the torsional vibration frequency of shafting is shown in the table below, which avoids the range of 45-55 and 95-105 to meet the requirements of the specification.

Table 2. Torsional vibration frequency of six-cylinder six-exhaust steam shafting.

Order	1	2	3	4	5	6	7	8
Frequency(Hz)	10.98	16.98	19.46	24.94	34.89	68.43	129.84	141.72

2.3 Analysis of economic indicators

Because the unit adopts the six-cylinder six-exhaust scheme, the exhaust area of the low-pressure cylinder is increased, and the flow capacity is improved at the same time. The back pressure of the steam turbine is reduced from the original 3.8kPa to 2.9kPa, which improves the thermal efficiency of the cycle. Compared with the five-cylinder four-exhaust and 3.8kPa back pressure scheme, the main technical indicators are shown in the following table:

Table 3. Comparison of main economic indicators.

Parameters	Six-cylinder six-exhaust scheme	Five-cylinder four-exhaust scheme
Unit output /MW	1000	1000
Main steam pressure /MPa	30	31
Main steam temperature/℃	600	600
Main steam flow/t·h-1	2541	2771
First reheat steam pressure /MPa	10	10.7
First reheat steam temperature /℃	620	620
Second reheat steam pressure /MPa	3.3	3.2
Second reheat steam temperature /℃	620	620
Exhaust steam pressure /kPa	2.9	3.8
Exhaust steam flow /t·h-1	1331	1440
Final feed water temperature /℃	325	328
Unit heat rate /kJ·kWh-1	6949	7024

It can be seen from Table 3 that the heat consumption rate of the five-cylinder four-exhaust scheme unit is 7024kJ/kWh. The heat consumption rate of the optimized six-cylinder six-exhaust scheme unit is 6949kJ/kWh, saving 2.28g/kWh of standard coal consumption for power generation.

2.4 Equipment manufacturing cycle

The steam turbine equipment manufacturer needs to improve the flow efficiency of the low-pressure cylinder by optimizing the airfoil of the last stage and redesigning the stability of the shafting. Moreover, the working capacity of the high-pressure cylinder, ultra-high-pressure cylinder and medium-pressure cylinder should be calculated. It is bound to increase the production cycle. It is conservatively estimated that the six-cylinder six-exhaust scheme will increase by 4 months compared with the five-cylinder four-exhaust scheme.

3 Benefit analysis

3.1 Comparative analysis of initial investment

Compared with the five-cylinder and four-exhaust scheme, the six-cylinder six-exhaust scheme needs to add a low-pressure cylinder, which brings additional civil engineering, and the corresponding auxiliary equipment, pump set, and circulating water pipeline also need to be added. See the table below for details. Overall, an additional investment of 66.36 million yuan is required.

Table 4. Investment comparison of two design schemes.

Scheme	Low pressure cylinders and accessories	Main factory building	Main factory building	Hydraulic machinery and pump set	Circulating water pipe
Six-cylinder six-exhaust scheme	+5500	+680	+120	+163	+173
Five-cylinder four-exhaust scheme	0	0	0	0	0

3.2 Coal cost analysis

According to the annual power generation utilization hours of 5,500 hours and the annual power generation of one generator set is 5.5 billion kWh, the six-cylinder six-exhaust scheme can save about 12,540 tons of standard coal every year. Calculated at 500 yuan per ton of standard coal, the annual cost of coal burning can be saved by about 6.27 million yuan.

Table 5. Comparison of heat consumption rate, coal consumption and operating cost of a single unit in the two schemes.

Design scheme	Average annual heat consumption rate of power generation /$kJ\cdot kWh^{-1}$	Coal consumption /$g\cdot kWh^{-1}$	Difference in coal consumption for power supply/ $g\cdot kWh^{-1}$	Average annual standard coal consumption difference / 10,000 tons	Average annual operating cost difference/10,000 RMB
Six-cylinder six-exhaust scheme	6949	259.8	benchmark	0	0
Five-cylinder four-exhaust scheme	7024	262.08	+2.28	+1.254	627

3.3 Comprehensive benefit analysis

The minimum annual cost comparison method is used to analyze the investment and coal-fired cost of the two schemes. The formulas are as follows.

$$N_F=i(1+i)^n\times K/((1+i)^n-1)+C$$

In the formula: NF is the annual cost, ten thousand yuan; K is the present value of the investment, ten thousand yuan; n is the economic operation period of the equipment, taking 25 years; C is the converted annual operating cost, ten thousand yuan; i is the discount rate.

Table 6. Comparison of the annual cost of a single unit in the two schemes.

Scheme	Fuel cost/10,000 yuan	Initial investment/10,000 yuan	Average annual cost difference/10,000 yuan
Six-cylinder six-exhaust scheme	-627	5500	0
Five-cylinder four-exhaust scheme	benchmark	benchmark	benchmark

Through the calculation of the minimum annual cost method of the two schemes, it can be seen that the six-cylinder six-exhaust steam scheme invests about 55 million yuan more than the five-cylinder four-exhaust steam scheme, and saves about 6.27 million yuan in coal burning costs every year. After 8.8 years, the investment cost can be recovered. Profitable from year 9.

3.4 Environmental benefit analysis

In terms of environmental protection and energy conservation, the two units of the six-cylinder six-exhaust scheme save 25,080 tons of standard coal annually, which is equivalent to reducing emissions of 8,444 tons of soot, 515 tons of sulfur dioxide, 109 tons of nitrogen oxides, and 69,472 tons of carbon dioxide. The environmental benefits are significant.

4 Conclusion

(1) Compared with the five-cylinder four-exhaust scheme, the six-cylinder six-exhaust scheme adds one low-pressure cylinder. Although the shafting length increases, the stability problem can be effectively solved by adjusting the expansion dead point.

(2) The six-cylinder six-exhaust solution can reduce the back pressure to 2.9kPa, and save about 2.28g/kWh of standard coal every year, which is equivalent to about 12,540 tons of standard coal. It has very good social benefits.

(3) In terms of environmental protection and energy saving, the six-cylinder six-exhaust solution reduces a large amount of pollutant emissions to the atmosphere every year, which has high benefits for protecting the environment.

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