Study on the Optimization of Steam Turbine Exhaust Channel Based on Adding Diversion Device

Chunzhen Qiao¹*, Chengfeng Zhu¹, Lanqing Su¹ and Kuifang Wan²

¹North China University of Technology, Beijing, 100144, China
²China Datang Corporation Science and Technology Research Institute, Beijing, 102206, China
*qcz@ncut.edu.cn
*Corresponding author’s e-mail: joecz1221@sina.com

Abstract: This paper studies the problems of high exhaust pressure and low economic efficiency caused by the uneven flow field at the exit of the steam turbine exhaust channel. This paper uses CFD simulation software to carry out numerical simulation on the steam turbine exhaust passage, and obtains a layout of the guide device that can greatly improve the uniformity of the flow field at the exit of the exhaust passage. This optimization scheme was applied to a domestic 600MW steam turbine unit for performance comparison and economic analysis before and after optimization. The results show that the average pressure of the condenser drops by about 0.704kPa. The coal consumption for power generation drops by about 0.525g/kWh. The annual standard coal saving is about 1729t. Therefore, installing a suitable diversion device can improve the operating efficiency of the unit, and has better economical efficiency and energy saving and emission reduction effects.

1. Introduction
The exhaust channel of the steam turbine is mainly composed of the exhaust cylinder and the condenser throat. The complex and diverse internal equipment of the turbine results in extremely uneven distribution of the outlet flow field, which affects the economy and safety of the condenser. There have been many studies on aerodynamic performance of exhaust cylinders at home and abroad. Michal [1], Tindell [2], etc. studied the effects of changes in the shape, size, and inlet air flow of the exhaust cylinder on its aerodynamic performance, and found that the efficiency was optimal when the inclination of the upper half of the exhaust channel was 15°. Zhang Di [3] studied the influence of inlet speed conditions on the aerodynamic performance of steam turbine exhaust cylinders, and found that the exhaust gas loss coefficients for the three inlet speeds are, in order, DC operation condition, weak rotation operation condition, and strong rotation operation condition. However, many studies at home and abroad have not considered the actual working conditions in engineering practice, which makes it impossible to simulate accurate flow conditions. Therefore, this article takes a domestic 600MW steam turbine as a prototype, determines the size of the model according to the site size, numerically simulates the internal components, analyzes the flow field diagram, pressure diagram, etc., gives an optimization plan, and finally implements it into the actual project. Analyze the test results in actual engineering, and finally judge the feasibility of the optimization scheme.
2. Theory and method
Optimizing the low-pressure exhaust cylinder passage is one of the effective ways to reduce the unit energy consumption and improve the unit efficiency [4]. There are two main ways to optimize it: one is to add various types of deflectors in the exhaust channel; the other is to optimize the geometric structure parameters of the exhaust channel [5]. The method used in this paper is to install a stainless steel diversion device in the original structure to make the outlet steam velocity distribution reasonable and reduce the exhaust vortex [6]. Ultimately reducing the exhaust pressure and improving the efficiency of the unit has great promotion value.

It is proposed to change the outlet flow field distribution by adding corresponding deflectors at the entrance, reduce the vortex area and high-speed steam flow area, make the outlet flow field distribution more reasonable, and achieve enhanced heat transfer of condenser tube bundles and ultimately reduce exhaust. The purpose of stress [7-8]. To this end, deflectors are installed at different positions in the exhaust cylinder, near the exit, etc., and the exhaust passages of different installation schemes are modeled and numerically simulated to determine the best optimization scheme based on the exit flow field.

The final solution is to install two deflectors in the exhaust cylinder. The first one is 8000mm in length and 369mm in height. It is located 340mm from the end wall and is symmetrically arranged about the center line. The second block has a length of 7040mm and a height of 369mm. It is located 400mm from the end wall and 270~300mm above the expansion joint outlet section. Two deflectors are placed side by side at a distance of 300mm from the condenser inlet. The arrangement is shown in Figure 1.

![Figure 1. Schematic diagram of the deflector position of the optimization scheme](image)

3. Experiments and results
3.1. Simulation results of optimization scheme
In order to verify the influence of the low-pressure cylinder exhaust and deflector on the steam exhaust of the turbine, a numerical simulation was performed on a model incorporating a deflector. By observing the velocity images of the entrance and exit of the simulation experiment, it can be found that the installation of the deflector breaks the vortex motion and the vortex radius decreases. At the same time, the scattered vortices will not be collected in large quantities and eventually become small vortices. This reduces the residual speed kinetic energy loss of the air flow during transportation, and the pressure loss is also reduced, and the flow rate of the fluid passing through the deflector is evenly dispersed on both sides. Comparing Figure 2. and Figure 3, it is found that the optimized flow field in the original channel (dark blue area in the figure, the speed is below 10m/s and the speed in the orange area exceeds 100m/s), the area of the low speed area is significantly reduced, and the speed value of the highest speed is also by the drop. Under the optimized steam flow field distribution, the reduction of vapor resistance makes the flow field distribution more uniform.
3.2. Test results of optimization scheme

In order to verify the reliability of the optimization scheme, according to Standards for steam surface condensers tenth edition Heat exchange Institute (HEI) 2006 and other standards, the optimization scheme was applied to a 600MW unit, and performance tests were performed on the condenser before and after optimization to determine its thermal characteristics.

This test was applied to a supercritical, once-reheated, single-shaft, three-cylinder, four-exhaust, condensing 600MW steam turbine. The condenser is a double back pressure, double shell, single flow, surface type condenser. The steam turbine rated main steam temperature is 566°C, and the rated main steam pressure is 24.2MPa. The steam turbine rated exhaust pressure is 5.2kPa, and the rated feed water temperature is 274.6°C. The condenser pressure is 5.2kPa. The cooling area is 36,000 square meters.

In order to verify the influence of the low-pressure cylinder steam deflector device on the steam turbine exhaust, the performance test of the steam turbine condenser before and after the deflector installation was performed. Before the low-pressure cylinder exhaust channel is optimized, the unit load is 601.9MW and the main steam temperature is 566.2°C. After the transformation, the unit load is 601.4MW and the main steam temperature is 560.9°C. The performance comparison results of the remaining condensers are shown in Table 1.

| Total heat load (MJ/h) | Total cooling water temperature rise (°C) | Low-pressure condenser pressure (kPa) | High-pressure condenser pressure (kPa) | Condenser average pressure (kPa) |
|------------------------|----------------------------------------|--------------------------------------|---------------------------------------|---------------------------------|
| Before                 | 2577272                                | 8.728                                | 3.238                                 | 3.951                           | 3.579                           |
| After                  | 2574190                                | 8.729                                | 3.832                                 | 4.780                           | 4.283                           |

It can be seen from Table 1 that the pressure of the low-pressure condenser is reduced by 0.594 kPa before and after the modification. The pressure of the high-pressure condenser is reduced by 0.829 kPa.
The average pressure of the condenser is reduced by 0.704 kPa. The difference in total temperature rise of cooling water is small, and the difference in total heat load is small.

According to the requirements of the specification, the temperature and flow rate of the circulating water inlet should be corrected for the test condenser pressure to the design circulating water inlet temperature and flow. The test results of 600MW load conditions were revised to the cooling water inlet temperature of 21.7°C and 33°C, respectively, and the flow rate was 70711m³/h [9]. The relationship between the average pressure of the condenser and the heat load of the condenser is shown in Figure 4. and Figure 5.

Figure 4. Relationship between average pressure of condenser and heat load (21.7°C)

Figure 5. Relationship between average pressure of condenser and heat load (33°C)
Taking the total heat load of the condenser at 2574190MJ/h as a reference, the average pressure of the condenser after the optimization of the low-pressure cylinder exhaust passage is lower than that before the modification at the cooling water inlet temperature of 21.7°C and the cooling water flow of 70711m³/h. About 0.229kPa; at the cooling water inlet temperature of 33°C and the cooling water flow of 70711m³/h, the average pressure of the condenser after the optimization of the low-pressure cylinder exhaust passage is reduced by about 0.355kPa compared with that before the modification.

Analysis of the economics of the unit, usually the exhaust pressure of large units is reduced by 1kPa, and the heat consumption rate is reduced by about 1 percentage point [10]. According to actual engineering tests, it is expected that after the exhaust passage is optimized, the exhaust pressure can be reduced by 0.2kPa.

The expression of coal consumption reduction is:

\[ P = \eta \times \alpha \times P_e \]  \hspace{1cm} (1)

formula: \( P \) is the decrease in coal consumption, g/kWh; \( \eta \) is the heat consumption rate; \( \eta \) is the decrease percentage; \( P_e \) is the exhaust pressure, kPa.

According to the performance test of the unit, the heat consumption rate of the unit is about 7700kJ/kWh, the percentage reduction is, and the exhaust pressure is 0.2kPa. According to formula (1), the coal consumption reduction after power generation can be obtained by optimization.

Savings of standard coal:

\[ G = \frac{P_c \times t \times P}{\eta_1 \times \eta_2} \]  \hspace{1cm} (2)

formula: \( G \) is the standard coal saving, kg; \( P_c \) is the unit load, W; \( \eta_1 \) is the boiler efficiency; \( \eta_2 \) is the pipeline efficiency; \( t \) is the operating time, h.

The operating time of a 600MW unit according to the circulating water temperature exceeding 20°C is 5000 hours. The boiler efficiency and pipeline efficiency are 92% and 99%, respectively. According to formula (2), 1729 tons of standard coal can be saved annually.

If the unit price of standard coal for power generation is 800yuan per ton, the annual fuel cost will be 1,383,200yuan. Since this optimization technology does not require any operation and maintenance costs, the investment payback period is only about 1 year. At the same time, one ton of standard coal was burned to emit 2.2 tons of CO₂, and annual carbon dioxide emissions were reduced to 3803 tons. It can be seen that both economic and social benefits are very significant.

4. Conclusion

- The final optimization scheme of the exhaust channel is to install two deflectors in the exhaust cylinder. The result of the simulation is that under the optimized steam flow field distribution, the reduction of steam resistance makes the flow field distribution more uniform. Adding a diversion device can reduce the heat transfer end difference of the condenser and improve the efficiency of the steam turbine.

- Applying this optimization scheme to the actual project, it was found that the pressure of the main steam decreased, the heat load of the condenser increased, the average pressure of the condenser decreased, and the unit efficiency was improved.

- After the transformation of the unit, the coal consumption for power generation will decrease by about 0.525g / kWh. The annual saving of standard coal is about 1729 tons. The annual carbon dioxide emission reduction is 3803 tons. The annual fuel cost saving is about 1.382 million yuan. Therefore, this optimization scheme has better economic efficiency and energy saving and emission reduction effects.

Acknowledgments

This study was financially supported by General project of science and technology plan of Beijing Municipal Commission of Education (110052971921/069).
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