Analysis and Treatment of Abnormal Pressure of Shaft Seal of Small Steam Turbine

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Abstract. In the commissioning of power plant, this paper finds that the shaft seal pressure of small steam turbine does not match the shaft seal pressure of steam turbine, and the shaft seal pressure of small steam turbine is high. On the basis of on-site verification and theoretical calculation, the problem of abnormal shaft seal pressure of small steam turbines was solved by modifying the steam turbine shaft sealing point access point and increasing the small turbine shaft seal overflow device, which provided a solution for similar problems in the future.

1. Introduction
The turbine of a power plant is N600-24.2/566/566 supercritical, primary reheat, four cylinders, four exhaust and double back pressure condensing turbine (hereinafter referred to as main turbine) designed and manufactured by Beizhong Alstom Electrical Equipment Co., Ltd. The turbine is equipped with two 50% capacity steam feed pumps, feed pump small turbine is G16-1.0 condensing feed pump turbine (hereinafter referred to as small turbine) manufactured by Dongfang Steam Turbine Co., Ltd. A vacuum system is shared between the small turbine and the main turbine. The exhaust steam of the small turbine enters the main turbine condenser through the butterfly valve.

2. Problems in shaft seal system of small turbine
The shaft seal system has two steam supply sources, one from the cold re-piping and the other from the auxiliary steam header. The steam source of the small turbine shaft seal derives from the steam supply pipe of the main turbine shaft seal, and the steam return of the small turbine shaft seal is incorporated into the main turbine shaft seal steam return pipe, and finally into the shaft seal heater. The main turbine shaft seal system is equipped with overflow device, which is connected to 7B low-pressure heater through pipeline. In unit commissioning, the following problems exist in the small turbine shaft seal system: 1) the small turbine shaft seal pressure does not match the main turbine shaft seal pressure; 2) in the high load stage of the unit, the small turbine shaft seal pressure is high.

3. Shaft seal pressure mismatch
3.1. Problems arise
According to the design data, the design pressure of the main turbine shaft seal system is 3 kPa, and that of the small turbine shaft seal system is 27 kPa. Since the steam source of the small turbine shaft seal derives from the steam supply pipe of the main turbine shaft seal, the pressure of the small turbine shaft seal can not exceed 3 kPa. When the small turbine establishes vacuum, a large amount of air will...
enter the main turbine condenser through the small turbine exhaust butterfly valve, resulting in a rapid decrease in the main turbine vacuum.

3.2. Problem analysis

From the above analysis, it can be seen that the mismatch between the main turbine shaft seal pressure and the small turbine shaft seal pressure is due to the small turbine shaft seal steam source derives from the steam supply pipe of the main turbine shaft seal. Therefore, the small turbine shaft seal steam source access point is reformed. After on-site exploration and technical discussion, there are four schemes for small turbine shaft seal steam source access.

| No. | Access point                                                                 | Advantages/disadvantages                                                                 |
|-----|-------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------|
| 1   | Access point on the pipe from auxiliary steam header to main turbine shaft seal | Pipe layout is convenient; pipe design size can not meet the flow required for small turbine shaft seal. |
| 2   | Access point on the pipe from cold re-pipeline to main turbine shaft seal      | It does not provide the shaft seal steam needed for small turbine during unit start-up.   |
| 3   | Access point on the cold re-pipeline                                          | Pipe layout is inconvenient.                                                             |
| 4   | Access point on the auxiliary steam header                                    | Steam parameters is suitable, pipe layout is convenient, and all-weather supply of shaft seal steam for small turbine. |

From Table 1, it can be seen that in scheme 1, the pipe layout is convenient, but the dimension of pipe from auxiliary steam header to the main turbine shaft seal system is designed for the main turbine shaft seal pressure, which cannot meet the steam flow required for the normal operation of small turbine shaft seal system, so they are abandoned. Scheme 2 is the same as scheme 1. When the unit starts, it cannot provide the steam needed by the small turbine shaft seal system, so scheme 2 and scheme 2 are abandoned. Scheme 4 can make up for the shortcomings of scheme 1, scheme 2 and scheme 3, so scheme 4 is chosen.

4. High shaft seal pressure of small turbine

4.1. Problems arise

According to scheme 4, the steam source access point of the small turbine shaft seal was reformed. During the subsequent unit trial operation, after the unit load reached 300 MW, the small turbine shaft seal intake steam regulating valve gradually closed down. When the unit load reaches 400 MW, the intake control valve is completely closed, and the pressure of the small turbine shaft seal is maintained at about 30 kPa. However, with the further increase of unit load, the pressure of small turbine shaft seal gradually rises to 80 kPa, which exceeds the design value of small turbine shaft seal pressure, threatening the safe operation of small turbine.

4.2. Problem analysis

4.2.1. Inspection and analysis of equipment

When the unit load reaches 300 MW, the inlet steam control valve of the small turbine shaft seal automatically closes down, which indicates that the small turbine shaft seal starts to enter the self-sealing state when the unit load reaches 300 MW. Generally speaking, when the shaft seal system enters the self-sealing state, with the increase of load, the inlet steam regulating valve of the shaft seal will be gradually closed down until the whole shutdown, and the overflow valve of the shaft seal will be opened automatically to maintain the pressure of the shaft seal near the design value. Aiming at the problem of high pressure of small turbine shaft seal after unit load reaches 400 MW, the following four factors are analyzed.

| No. | Checkpoint                | Inspection result                                                                 |
|-----|---------------------------|-----------------------------------------------------------------------------------|
| 1   | Pipe layout               | The axle seal return pipe of the small turbine is merged into the main turbine return pipe, and the inclination angle of the pipe meets the design requirements. The main |
valve leakage pipe of the small turbine is merged into the main return pipe of the main turbine, and the regulating valve leakage pipe of the small turbine is merged into the high-pressure end seal intake pipe of the small turbine. No other pipes are merged into axle seal piping system of small turbine.

2 Labyrinth clearance
Carefully check the seal clearance of small turbine turbines, the dimensions meet the requirements of the manufacturer's instructions. When the unit load is 600MW, the rated output of one shaft fan is rated, the pressure of the small shaft seal system is 73kPa, the rated output of the two shaft fans is at the same time, and the pressure of the small shaft seal system is 67kPa.

3 Axial fan
When the unit load is 600MW, the rated output of one shaft fan is rated, the pressure of the small shaft seal system is 73kPa, the rated output of the two shaft fans is at the same time, and the pressure of the small shaft seal system is 67kPa.

4 Overflow device
None.

It can be seen from Table 2 that in the inspection of item 1, the misplacement of axle seal pipeline of small turbine can be excluded. From the inspection results of item 2, the seal clearance of the shaft seal system of small turbine meets the design requirements and can be excluded. In the inspection of item 3, it can be seen that in the high load section of the unit, increasing the output of the shaft plus fan can reduce the pressure of the shaft seal of the small turbine. Item 4 was inspected and the equipment instructions and design drawings were consulted. There was no overflow device in the small turbine shaft seal system. In summary, especially the inspection of item 3, it can be seen that the problem of high pressure of small turbine shaft seal can be solved by changing the return steam structure of small turbine shaft seal system.

4.2.2. Retrofit analysis of return steam structure
Generally, there are two schemes to change the return steam structure of small turbine shaft seal system.

| No. | Retrofit component                  | Advantages/disadvantages                                                                 |
|-----|-------------------------------------|-----------------------------------------------------------------------------------------|
| 1   | Shaft fan and return steam pipe     | Re-purchasing shaft fan and steam return pipe takes a long time and costs a lot. The influence of equipment modification on the main turbine shaft seal system should also be considered. The overflow device is added to the existing small turbine shaft sealing system, the transformation cost is small and the transformation time is short, and the pipe arrangement and the overflow steam are to be considered. |
| 2   | Overflow device                     | None.                                                                                    |

From Table 3, it can be seen that it is feasible to install overflow assembly to the small turbine shaft seal system to solve the problem of high pressure of small turbine shaft seal in the high load range of the unit. For scheme 2, the location of the overflow steam after the overflow device is installed should be considered. In order to recover the working fluid and heat and improve the operation economy of the unit, it is decided that the overflow steam from the shaft seal of the small turbine will be diverted to the low-pressure heater.

4.2.3. Selection and analysis of low-pressure heater
The small turbine shaft seal overflow steam enthalpy is lower than the 6-stage regenerative extraction enthalpy, higher than the 7-stage and 8-stage regenerative extraction enthalpy, and No.7 and No.8 low-pressure heater extraction parameters and the small turbine shaft seal steam parameters similar. Therefore, the small turbine shaft seal overflow pipe has the option of introducing the low pressure heater No.7 and the low pressure heater No.8. On the basis of the heat balance diagram of the unit design working condition, the correlation analysis is carried out on the basis of the principle of equivalent enthalpy drop, taking the overflow steam exhaust of the small turbine shaft seal as the benchmark. Relevant parameters of unit design conditions are shown in Table 4.

| Symbol      | Item                                      | Value                  |
|-------------|-------------------------------------------|------------------------|
| $\Delta H_f$| Small turbine shaft seal overflow recovery work | -                      |
| $H$         | Equivalent enthalpy drop of new steam     | 1238.8kJ/kg            |
| $q$         | Heat consumption value of unit            | 7570kJ/(kWh)           |
Relative variation of device efficiency $\delta \eta_i$
Relative change value of unit heat consumption $\delta q_i$
Overflow share of small machine shaft seal $a_f$
Enthalpy of steam overflow from small machine shaft seal $h_f$
Exhaust enthalpy $h_n$
Enthalpy of 7-stage regenerative extraction $h_7$
Enthalpy of 8-stage regenerative extraction $h_8$
7-stage regenerative steam extraction efficiency $\eta_7$
8-stage regenerative steam extraction efficiency $\eta_8$

From the principle of equivalent enthalpy drop, it can be seen that the overflow steam from the shaft seal of the small turbine is diverted to No. $j$ low-pressure heater, which will reduce the extraction steam from No.$j$ low-pressure heater, thus obtaining the recovery work $\Delta H_f$ of the overflow from the shaft seal of the small turbine. The relevant formulas are as follows:

$$\Delta H_f = a_f \left[ \eta (h_f - h_f) + (h_f - h_n) \right]$$

$$\delta \eta_i = \Delta H_f \left( H + \Delta H_f \right) \times 100\%$$

$$\delta q_i = \delta \eta_i \times q$$

By substituting the relevant data in Table 5 into formulas (1), (2) and (3), the following data can be obtained:

$$\delta q_f = 7570 \times \frac{2.89}{1238.8 + 2.89} \times 100\% = 17.62 \text{ kJ/kWh}$$

$$\delta q_f = 7570 \times \frac{1.36}{1238.8 + 1.36} \times 100\% = 8.31 \text{ kJ/kWh}$$

According to the above data, when the unit load is 600 MW, the same shaft seal overflow steam is discharged into No.7 low-pressure heater, the relative value of unit heat consumption decreases by 17.62 kJ/kWh; when discharged into No.8 low-pressure heater, the relative value of unit heat consumption decreases by 8.31 kJ/kWh. Therefore, the small turbine machine shaft seal overflow steam is selected to lead to No.7 low-pressure heater.

### 4.3. Treatment measures

#### 4.3.1. Lead to 7B low-pressure heater

The overflow steam of the main turbine shaft seal (when the unit is under high load) is discharged into the 7B low-pressure heater, and install $\varnothing 57*3.5$ mm pipe on the pipe after the small turbine shaft seal intake steam regulating valve, and arrange the corresponding control valve, manual valve and drainage point. The installed shaft seal overflow pipe is connected to the main axle seal overflow pipe (after the main shaft seal overflow control valve). After the implementation of the scheme, the operation of the equipment is monitored at 600 MW of the unit, as shown in Table 5.

**Table 5. Small turbine shaft seal overflow steam is led to the main shaft seal overflow pipe front/back comparison table**

| No. | Monitoring objects | 600 MW status |
|-----|--------------------|----------------|
| 1   | Shaft seal pressure of small turbine | The pressure of small turbine shaft seal is basically maintained at 78 kPa. | The pressure of small turbine shaft seal is basically maintained at 60 kPa. |
| 2   | No.7 low-pressure heater | There is no disassembly of the water side of the No.7 low-pressure heater. | The water side of the No.7 low-pressure heater is frequently disassembled. |

From Table 5, it can be inferred that when the unit load is 600 MW, the steam flow rate discharged into 7B low-pressure heater exceeds the design capacity of 7B low-pressure heater after the small
turbine shaft seal overflow steam is diverted to the main turbine shaft seal overflow pipe. Therefore, it is necessary to improve the scheme of the small turbine shaft seal overflow steam leading to the main turbine shaft seal overflow pipe, and lead the small turbine shaft seal overflow steam to 7A low-pressure heater.

4.3.2. Lead to 7A low-pressure heater
After connecting the shaft seal overflow pipe of the small turbine to the 7A low-pressure heater steam extraction pipe, the operation of the equipment is monitored at 600 MW of the unit, as shown in Table 6. It can be seen from Table 6 that after the small turbine shaft seal overflow steam is led to the 7A low-pressure heater extraction pipe, the small turbine shaft seal pressure can be controlled near the design value in the high load range of the unit, and the water side of the No.7 low-pressure heater is not disjunction occurred.

Table 6. Small turbine shaft seal overflow steam is led to 7A low-pressure heater extraction pipe front/back comparison table

| No. | Monitoring objects | 600 MW status |  |
|-----|-------------------|---------------|---|
|     | The situation of the small turbine shaft seal overflow steam is led to the main turbine shaft seal overflow pipe | The situation of the small turbine shaft seal overflow steam is led to 7A low-pressure heater extraction pipe |
| 1   | Shaft seal pressure of small turbine | The pressure of small turbine shaft seal is basically maintained at 60 kPa. | The pressure of small turbine shaft seal is basically maintained at 30 kPa. |
| 2   | No.7 low-pressure heater | The water side of the No.7 low-pressure heater is frequently disassembled. | There is no disassembly of the water side of the No.7 low-pressure heater. |

5. Conclusion
- The shaft seal pressure of the small turbine is matched with the pressure of the main turbine shaft seal. The steam seal of the small steam turbine shaft seal can be taken from the steam main pipe of main turbine shaft; if the shaft seal pressure of the small turbine does not match the pressure of the main turbine shaft seal, the small turbine shaft seal steam supply source should be considered separately in the design.
- The discharge of the small turbine shaft seal overflow steam into the low-pressure heater should be based on the theoretical calculation, and also consider the design parameters of the low-pressure heater, avoid the derivation problem of the low-pressure heater.

Reference
[1] Lin Wan-chao. Energy-saving theory of thermal system in thermal power plants[M]. Xi'an: Xi'an Jiaotong University Press, 1994.
[2] WEI Xi-feng. Defect analysis and improvement measures of 600MW steam turbine shaft seal system[J]. Electrical Equipment, 2006(5):55-57.
[3] HUANG Tai-ming. Optimization of operation mode of 600MW steam turbine shaft seal system[J]. Huadian Technology, 2015(6):71-75.
[4] XUE Jiang-tao. Analysis and countermeasure of the shaft seal system of 1000MW secondary reheat steam turbine[J]. Electric Power, 2017(1):33-36.
[5] LIU Hong-wei. Research on economic analysis method of steam turbine shaft seal system[J]. Electric Power Science and Engineering, 2008(5):23-24.