Diagnosis and elimination of a typical serious rubbing fault of steam turbine

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Abstract. During the operation of a steam turbine in a power plant, the no.3 bearing of the LP rotor suddenly vibrated strongly, which caused the protection action and the turbine tripped. During the maintenance it was found that serious rubbing occurred between the impeller of the LP rotor and diaphragm gland in the LP cylinder. Through inspection and analysis, the location and cause of the rubbing were found, and corresponding treatment was carried out. During the start-up process after maintenance, the vibration of no.1 bearing of HP/IP rotor increased to trip value. In order to eliminate the rubbing of HP/IP rotor, the appropriate warm-up speed was selected and the speed control method was adopted to make the unit start to the working speed and put into normal operation.

1. Introduction
Rubbing between rotating and stationary parts of steam turbine is one of the important reasons for abnormal vibration of turbine bearings. During the start-up phase of the unit, the concentricity between the HP/IP rotor and the cylinder is constantly changing. Due to the stronger dynamic stiffness of HP/IP rotor support system, the relative vibration of rotating shaft is greater, and the radial clearance of HP/IP rotor part is the smallest in the shaft system, the rubbing during the start-up process of steam turbine mostly occurs on the HP/IP rotor[1].

On the contrary, the LP rotor is not easy to rub during start-up. However, under the condition of high load operation, the deformation and deviation of the LP cylinder are easy to cause uneven clearance between the impeller of the LP rotor and the diaphragm gland, cover band gland, shaft gland, oil baffle, and lead to rubbing.

2. Shafting structure and operation parameters during tripping
The shafting of this unit is composed of HP/IP rotor, LP rotor and GEN rotor. The HP/IP rotor and LP rotor are three-bearings support structure, and they are connected by rigid coupling. The semi- flexible coupling is used between the LP and GEN rotor. The unit has 5 bearing blocks, as shown in Figure 1.

![Figure 1. The structural diagram of the unit shafting.](image-url)
Before the unit trip action, the load was 100MW, the unit operated in coordinated mode, the main steam pressure was 13.16MPa, the main steam temperature was 538.8℃. The A/B induced draft fans, A/B primary air fans, and A/B secondary fans were all in normal operation. Furnace pressure was -80Pa, condenser vacuum was -94.5kpa, high pressure differential expansion was 1.59mm, low pressure differential expansion was 5.38mm, axial displacement was -0.058mm, thermal expansion was 18.33mm. Shaft vibration, thrust pad temperature, bearing metal temperature and oil return temperature of the unit were all within the normal range[2-3].

When the turbine tripped, the boiler was in MFT state and the generator was disconnected due to the protection action of "large turbine vibration". According to the alarm history, the 3X shaft vibration and 3Y shaft vibration were 400.24μm and 400.24μm respectively (trip value: 254μm, alarm value: 127μm).

After the unit tripped and shut down, the manhole at the steam side of the condenser was opened and abnormal sound was heard in the LP cylinder. The last stage blades of the LP rotor were macroscopically inspected and no abnormality was found. And it was determined that the LP cylinder would be opened for inspection and then the quick cooling device was put into operation.

3. Analysis of rubbing point after inspection and method of maintenance treatment

After the cylinder temperature dropped below 150℃, the connecting pipe, LP outer cylinder and LP inner cylinder were hoisted away, all blades of the LP rotor were inspected, and no fracture was found. When the LP rotor is turned, there was still a rubbing sound in the LP inner cylinder. No abnormal condition was found when the HP/IP rotor was turned.

3.1. Defects found during inspection after shutdown

During the examination, it was found that in the reverse stage 5 of the LP rotor, the right side of the lower part of the steam baffle of the diaphragm was about 550mm long, it was lifted out of the groove and had heavy abrasion marks. The right side of the upper part of the steam baffle of the diaphragm was about 450mm long, it broke and fell off, and the fracture was new.

After checking the diaphragm gland at the lower part of the forward 6th stage of the LP cylinder, it is found that the interface of the right gland block is misplaced and the gland teeth are seriously worn. The arched cover bands of the last reverse stage of LP rotor were checked and found to be broken at 6 places (serial numbers: 4-5, 12-13, 16-17, 91-92, 97-98, 99-100). Cracks were found in 5 arched cover bands (serial numbers: 14-15, 19-20, 23-24, 51-52 and 61-62), of which 23-24 were original cracks and the other four were new cracks.

3.2. Mechanism analysis of rubbing vibration

According to the analysis of the rubbing parts, it is considered that the right side of the reverse direction and the left side of the positive direction of the LP inner cylinder appeared deflection during the thermal expansion. The clearance of the diaphragm gland of LP cylinder was getting smaller, and the rub between the LP rotor and the diaphragm glands made the shaft vibration of no. 3 and no.4 increased rapidly and caused the unit trip[4-5].

3.3. Targeted measures taken in subsequent maintenance

3.3.1. The diaphragm glands and steam baffles of LP cylinder were inspected comprehensively. The falling and damaged steam baffles were replaced and segmented argon arc welding was adopted to ensure the safety and reliability of the steam baffles.

3.3.2. According to the upper limit specified in the maintenance procedures, properly enlarged the clearance of diaphragm glands and steam baffles on the right side of the reverse direction and the left side of the positive direction of the LP inner cylinder.
3.3.3. The #1, #2 and #3 bearings were disassembled and comprehensively inspected, and the bearing top clearance was adjusted to the lower limit of the installation setting value.

3.3.4. The open welding and falling off of the locating pin of the LP inner cylinder was checked and eliminated, and the excessive clearance of the locating pin of the LP inner cylinder was reduced.

4. Vibration analysis and treatment during start up after maintenance

During the cold start-up of the unit after maintenance, when the unit was warmed up at a medium speed of 1500rpm, the operator found that the vibration of no.1 shaft was climbing and decided to speed up immediately. When the speed increased to 1810rpm, the vibration values of 1X and 1Y were 290μm and 148μm respectively, and the protection action tripped due to the excessive shaft vibration. The relevant operation parameters were checked after shutdown. The wall temperature of the upper and lower cylinders of the HP inner cylinder was 440℃/442℃, the wall temperature of the upper and lower cylinders of the IP cylinder was 432℃/421℃, the bending value of the rotor was between 0.05mm-0.08mm, and the metal temperature, thrust pad temperature and oil return temperature of each bearing were within the normal range, so put the turning gear into operation.

According to the vibration test data, the analysis shows that: due to the insufficient expansion of the cylinder in the cold start-up process, the HP/IP rotor slightly rubbed, so at 1500rpm, the vibration of no.1 shaft had climbing phenomenon. At that time, the correct way is to reduce the speed and warm up the turbine. But instead, the speed was forced to increase to 1810rpm, which was close to the critical speed of the HP/IP rotor (the calculated value of the first critical speed of the HP/IP rotor was 1843rpm), and caused strong resonance of the HP/IP rotor, the vibration no.1 shaft increased rapidly, which caused the turbine trip.

Based on the above analysis, the following control measures were taken when the unit started again: start warming up the unit at 1200rpm and continuously monitor the vibration for 30 minutes, when the variation value of no.1 shaft vibration at stable speed is less than 30μm, it indicates that the rub of HP/IP rotor has been eliminated, and the unit can continue to speed up. Otherwise, reduce the speed to 1000rpm and continue to warm up until the vibration value at the same speed remains relative stability.

After taking the above control measures, when the unit was started again, the speed was smoothly increased to 3000rpm. The BODE diagrams of no.1X and no.1Y shaft vibration of HP/IP rotor are shown in Figure 2. and Figure 3.

![Figure 2. The BODE diagram of no.1X shaft vibration.](image-url)
During the next operation of the unit, after months of observation, the vibration of no.3 and no.4 bearings of LP rotor could keep stable, and there was no serious rubbing phenomenon on LP rotor. The relevant shaft vibration data of the unit are shown in Table 1.

Table 1. The shaft vibration data of bearings of the unit.

|        | 1X/1Y (μm) | 2X/2Y (μm) | 3X/3Y (μm) | 4X/4Y (μm) | 5X/5Y (μm) |
|--------|------------|------------|------------|------------|------------|
| 3000rpm| 40/36      | 30/29      | 42/34      | 32/46      | 52/55      |
| 100MW  | 64/82      | 27/24      | 53/33      | 36/54      | 61/67      |

5. Conclusion
During the high load operation of steam turbine, if the expansion of LP cylinder is not uniform, rubbing between rotor and diaphragm is easy to occur. In serious cases it will lead to tripping. In the maintenance process, the targeted treatment method can eliminate the deflection expansion of LP cylinder. During the cold startup of the unit after overhaul, through reasonable control of the warmup speed and vibration value, the rubbing vibration of HP/IP rotor could be eliminated.

References
[1] Lu, S.Y., Wu, Z.F. (2020) Vibration fault diagnosis and case study of steam turbine generator set. Turbine Technology, 2020, 62(01): 81.
[2] Ge, J.X., Tao, Y.H., Hao, Q.F., Dai, F. (2019) Fault diagnosis and treatment of rubbing vibration of high and medium pressure rotors of 630MW steam turbine generator set. Power System Engineering, 2019, 35(06): 53-55+58.
[3] Zhang, Y.J. (2018) Comparative analysis of two typical rubbing faults of steam turbine. Shanxi Electric Power, 2018(02): 49-53.
[4] Zhang, X. (2017) Analysis diagnosis and treatment of high and medium pressure rotor vibration of steam turbine. Turbine Technology, 2017, 59(04): 303-305+309.
[5] Li, W.J., Wu, W.J., Ying, G.Y. (2017) Diagnosis and treatment of abnormal vibration of low pressure rotor of 630MW unit. Zhejiang Electric Power, 2017, 36(01): 54-57.