Research on vibration elimination of a 350 MW heat supply unit during cold start

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Abstract. A 350MW heat supply unit in a power plant encountered abnormal vibration of IP rotor bearing during cold start after overhaul. By analyzing the vibration data in the start-up process, the reason for abnormal vibration was found to be excessive vibration of IP rotor passing through critical speed and rubbing between IP rotor and casing. Through the field high dynamic balancing test and adopting the most suitable operation control mode of this type of heat supply unit, the abnormal vibration of the unit was eliminated.

1. Introduction
The unit is CC350-535/535-16.67 type double extraction and double adjustment condensing heat supply unit, with high and intermediate pressure split cylinders and rotating diaphragms used for industrial steam. The regulating butterfly valve is set on the connecting pipe of intermediate and low pressure cylinder to supply heating steam.

There are 8 supporting bearings in the unit, among which #1-#6 are turbine rotor bearings and #7-#8 are generator rotor bearings. The shafting structure is shown in Figure 1. The design value of critical speed of steam turbine is 1550rpm for high and intermediate pressure rotors and 1650rpm for LP rotor.

![Figure 1. The shafting structural diagram of the unit.](image)

2. First cold start process and vibration data after overhaul
During the overhaul of the unit, the high and intermediate pressure shaft seals were changed to brush type steam seals. During the cold start-up after overhaul, the vibration of bearings #3 and #4 exceeded the standard in the critical speed range of 1700rpm-1800rpm, and the start-up was difficult. Each time, it was necessary to warm up the unit at low speed, to start up and shut down many times. After running the barring gear for a long time, until the thermal expansion of steam cylinder reached 12.5mm, the start-up could be successful. It brought great trouble to the normal operation of the unit[1]. The following is the start-up process.
2.1 Speed up for the first time
Before the start-up, main steam pressure was 4.89MPa, main steam temperature was 330℃, the vacuum value was -95.6KPa. At 1302rpm, the shaft vibration of 2X was 162μm. At 1784rpm, the shaft vibration of 3X was 343μm, 4X was 271μm, the vibration of #4 bearing pedestal was 200μm. At 2964rpm, the shaft vibration of 3X was 305μm, 3Y was 236μm, 2X was 188μm, 2Y was 169μm.

When the speed dropped to 1729rpm after manual trip and shutdown, the shaft vibration of 3X was 406μm, 3Y was 176μm, 4X was 446μm, 4Y was 256μm.

2.2 Speed up for the second time
Opened the vacuum breaking door slightly and reduced the vacuum value to -87kpa, speeded up the unit to 600rpm for warm-up. Because the vibration continued to increase, the unit was shut down again. Put the barring gear into operation for more than 4 hours.

2.3 Speed up for the third time
At this time, when the unit was started to 1100rpm, it was warmed up for 20 minutes without high pressure heater. At 1719rpm, the shaft vibration of 3X was 491μm, 3Y was 221μm, 4X was 427μm, 4Y was 184μm. The unit was shut down due to large shaft vibration and protection action.

2.4 The fourth and fifth speed up
The protection setting value of shaft vibration of #2, #3 and #4 is modified to 450μm for the fourth speed up. At 1798rpm, the shaft vibration of 3X was 396μm, 3Y was 216μm, 4X was 356μm, 4Y was 161μm. The unit was shut down because the large deviation between the given speed and the actual speed value.

For the fifth speed up, when the shaft vibration of 2X and 2Y reached 500μm, the protection did not act, so the brake was tripped manually.

2.5 The sixth speed-up reached the working speed
When the main steam pressure was 5.2MPa and vacuum value was -87KPa, the sixth speed-up started. At 1802rpm, the shaft vibration of 3X was 345μm, 3Y was 185μm, 4X was 302μm, 4Y was 145μm.

When the speed increased to 2700rpm, the high-speed warm-up started. The temperature of upper and lower cylinder of HP cylinder were 238℃ and 238℃, respectively. The upper and lower IP cylinder temperatures were 111℃ and 102℃, respectively. The shaft vibration of 3X was 66μm, 3Y was 56μm, 4X was 47μm, 4Y was 31μm, the vibration of #4 bearing pedestal was 29μm. Then the steam turbine speeded up to 3000rpm, and all vibration values of the shafting were below the alarm value.

3. Analysis and treatment of the abnormal vibration
From the cold start-up process of the unit, it can be seen that due to the large vibration of bearing #2, #3 and #4 in the process of speed up, the turbine must be warmed up for many times, and the shutdown was repeated several times. The vibration problem has seriously affected the safe operation of the unit.

According to the analysis of the vibration test data of the unit, one of the important reasons for the excessive vibration of the IP rotor passing through critical speed was the large first-order mass unbalance. Therefore, a field dynamic balancing test of IP rotor was carried out. After calculation based on vibration data, 380g counterweights of the same phase were added in the balancing slots at both ends of the IP rotor[2-3].

The analysis shows that the clearance became smaller after the renovation of brush type steam seal of turbine, and the center changed due to insufficient expansion of IP cylinder during cold start-up, resulting in the rubbing between rotor and steam seal and causing abnormal vibration.

During the first cold start-up, the speed of the unit had reached 2964 rpm. And during the sixth speed-up after more than 7 hours of barring, the turbine speed reached 2700rpm safely. During more
than 1 hour high-speed warm-up, a large number of steam was supplied to the IP cylinder, and the temperature of the upper cylinder of the IP cylinder could reach above 280℃. The temperature difference between the upper and lower cylinders of the IP cylinder was very small. The shaft vibration of the #2, #3 and #4 gradually decreased from above the alarm value to less than 76μm. Based on the above analysis, the turbine can be driven to 2700rpm for high-speed warm-up during cold start-up. Therefore, detailed cold start-up measures are formulated as follows.

3.1 Inspection and parameter requirements before start-up
When the pressure of the boiler drum reaches 1MPa, the boiler should be inspected comprehensively to avoid missing the air valves and drain valves that should be closed, and the leakage point should be found in time. The main steam pressure should be 4.5MPa~5.0MPa, the main steam temperature 330℃~350℃, the vacuum -88kPa~-90kPa, and the rising rate should be 100rpm/min.

3.2 Vibration protection value during start-up
The shaft vibration protection setting value of #2, #3 and #4 bearings was temporarily changed to 360μm, with a delay of 5 seconds. The critical speed range was set to 650rpm ~ 950rpm, and 1200rpm ~ 2600rpm. The rising rate on critical speed range was set to 400rpm/min[4-5].

3.3 Operation of high pressure heaters and low pressure heaters
During cold start-up of the unit, the high-pressure and low-pressure heaters should not be put into operation temporarily. When the speed reaches 3000rpm and the vibration of the shafting is stable below alarm value, the heaters could be put into operation gradually.

3.4 Exhaust temperature and condenser vacuum
Before speed up, fully open the vacuum test valve, and manually open the vacuum breaking electric valve to make its opening percentage between 18% and 25%, and control the vacuum value at ~87KPa. When the turbine is warmed up for one hour at a constant speed of 2700rpm, attention must be paid to the increase of the exhaust temperature. It is necessary to adjust the vacuum breaking electric valve to control the maximum exhaust temperature not higher than 70℃. When the exhaust temperature reaches 80℃, the alarm shall be given, and the spray desuperheating device of LP cylinder shall be automatically opened and work normally. When the exhaust temperature reaches 121℃, the unit is not allowed to run continuously for more than 15 minutes. If the adjustment measures are invalid, the unit should be shut down immediately. During the whole warm-up period, the vacuum value should be controlled between -88KPa and -92KPa.

3.5 Speed up to working speed
When the turbine is warmed up at 2700rpm for more than 1 hour, the temperature difference between upper and lower cylinders of the IP cylinder shall not exceed the standard, and the vibration of #2, #3 and #4 bearings shall decrease to less than 76μm. The exhaust steam temperature should be lower than 60℃. Turn down or even close the vacuum breaking electric valve and vacuum test valve, and then speed up.

In the process of speed up, pay close attention to the deviation between the valve instructions of the high-pressure main steam valve, high-pressure control valve and the actual speed. If the deviation is large, the vacuum value or intake parameters shall be increased in time to reduce or even eliminate the deviation, so as to prevent the protection action from tripping due to the large speed deviation. After the speed reaches 3000rpm, if the shafting vibration is normal, adjust the water level of high and low pressure heaters in time and put them into automatic operation.

4. Start up and operation data after vibration treatment
After the field dynamic balancing test of IP rotor, the unit was started again. When the steam turbine passed through the first critical speed, the vibration value of the shafting was within 100μm.
According to the above-mentioned warm-up and speed-up control measures, the unit successfully reached the working speed of 3000rpm. The BODE diagrams of no.3X and no.4X shaft vibration of IP rotor are shown in Figure 2 and Figure 3.

After finishing electrical tests, the unit was connected to the grid. During the operation with load, the shafting vibrations were always maintained at an excellent level below 76μm. The relevant shaft vibration data of the unit are shown in Table 1.

|          | 1X/1Y (μm) | 2X/2Y (μm) | 3X/3Y (μm) | 4X/4Y (μm) |
|----------|------------|------------|------------|------------|
| 3000rpm  | 42/36      | 45/39      | 32/31      | 62/56      |
| 350MW    | 53/45      | 53/55      | 37/33      | 75/70      |

5. Conclusion
Based on the practical treatment experiences of a 350MW heat supply unit, this paper discusses the method to eliminate the abnormal vibration of the unit of cold start-up after overhaul. Through on-site dynamic balancing test and appropriate operation control mode, the abnormal vibration of the unit was eliminated. This method has reference significance for the vibration treatment of similar units.

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