Abnormal vibration analysis and treatment for No. 3 bearing bush of ultra-supercritical 1000MW turbine

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Abstract. When a power plant ultra-supercritical 1000MW steam turbine generator set was started in a cold state, the vibration value of NO.3 bearing bush exceeded the alarm value. Based on the mechanism of vibration, the fault diagnosis and troubleshooting of excessive vibration of the NO.3 bearing bush were carried out by consulting the historical operation trend and checking the maintenance records, and the cause of the fault was accurately analyzed. By adopting effective measures such as setting up the heating system of the middle pressure cylinder and setting up the starting steam parameters reasonably, the problem of excessive vibration value of the NO.3 bearing bush was completely solved and the hidden danger of equipment operation safety was eliminated.

Keywords: NO.3 bearing bush; excessive vibration; Fault diagnosis; Fault treatment.

1. Overview of equipment
The unit of a power plant is 2 1000MW ultra-supercritical units, and the steam turbine is N1050-25/600/600 ultra-supercritical, primary and intermediate reheat, uniaxial four-cylinder, four-row steam turbine and condensing steam turbine, and the middle and low pressure cylinders are all double-flow layout. Flow series is 45: high pressure cylinder is a double-row regulation stage, 8 pressure levels; The intermediate pressure cylinder has $2 \times 6$ pressure stages; The low pressure cylinder has $2 \times 2 \times 6$ pressure stages. The unit is designed as a high pressure cylinder starting mode, equipped with a high pressure bypass system, with a capacity of 30% B-MCR, which can only meet the starting needs of the unit and does not have the reheater protection function. When the quality and parameters of the main steam have the condition of flushing, open the high and medium pressure regulating valve at the same time, and pass the rotor of steam inlet impulse of the high pressure cylinder and the medium pressure cylinder. High pressure cylinder exhaust steam enter into the reheater, and then enter into the middle pressure cylinder work, exhaust to the condenser. No high row reverse check door is set in the exhaust pipe of the high pressure cylinder of the steam turbine. Before the steam turbine cold start, pre-heat the high - pressure cylinder, increase the adjustment metal temperature as far as possible. High pressure cylinder warm vapor source by adjacent machine four extraction (THA the steam parameters under the condition of 1.159 MPa, 392.8 °C), the unit and auxiliary steam header.
The shaft system of the unit is composed of the high-pressure rotor of the steam turbine, the medium-pressure rotor, the low-pressure rotor (A), the low-pressure rotor (B) and the generator rotor. All rotors are integral rotors without central holes, and the rotors are connected with rigid couplings. No.1 to NO.4 bearings in the shaft system of steam turbine generator set adopt tilting pad bearing, tilting pad bearing adopts 6-tile structure and is arranged symmetrically. No.5 to NO.10 bearings adopt oval bearing. Oval bearing is single side oil inlet with grooved upper tile structure. Bearing alloy joint surface adopts dovetail groove structure. The X and Y direction of the upper bush of each bearing is provided with a measuring device for axial vibration.

The thrust bearing is located in the NO.2 bearing seat between the high pressure cylinder and the middle pressure cylinder. and adopts the inclined plane type double thrust plate structure to bear the axial thrust and become the relative expansion dead point of the shaft system. The stator parts of the steam turbine maintain three fixed points (absolute expansion dead point) relative to the foundation through the horizontal key: first, the middle bearing box located between the middle pressure cylinder and the low pressure (A) cylinder; The other two are near the center line of low-pressure admission of low-pressure cylinder (A) and low-pressure cylinder (B) respectively. Horizontal keys at three fixed points limit the axial displacement of the cylinder. At the same time, longitudinal keys are arranged before and after the longitudinal center line of the front and middle bearing boxes and two low-pressure cylinders, which guide the cylinder to expand freely along the axial direction and limit the lateral deviation.

2. Overview of fault phenomena
Since the two units were put into operation, the vibration value of the NO.3 bearing bush was up to 150 μm (exceeding the alarm value of 125 μm) during the cold start-up process, which seriously affected the safety and stable operation of the units, and resulted in the prolonged cold start-up time, increased start-up costs and reduced start-up benefits.

3. Cause analysis of fault
3.1. Reasons analysis for excessive vibration value of NO.3 bearing bush
In the cold starting process of the unit, the shaft vibration value of NO.3 bearing bush was characterized by the following characteristics: the vibration of the unit increased gradually before the speed setting; after the speed setting, with the extension of time, the vibration gradually decreased and maintained a certain value.

From the perspective of the vibration trend after startup, there were roughly four different stages:
1) 12:00 ~ 16:00, the vibration value of the NO.3 bearing bush increased from 20 μm to 150 μm, the phase Angle appeared wave-like change and was always unstable.
2) Aft 20:00, the vibration value of the NO.3 bearing bush was kept at 150 μm and relatively stable after the set speed was set.
3) Aft 23:00, the vibration value of the NO.3 bearing bush started to decline slowly when the unit was running at rated speed.
4) After 8:00 on the second day, the vibration value of NO.3 bearing bush reduced to about 90 μm, and finally stable at 72 μm.

Seen from the trend of vibration characteristics, the excessive vibration of NO.3 bearing bush was mainly due to the expansion of the unit was not smooth, causing vibration value was on the rise. At this stage, expansion of blocked situation became more and more serious, and produced a certain action to touch the ground, with the extension of time, the expansion of the cylinder and rotor relative matching, movement touch ground gradually disappear, the vibration of NO.3 bearing bush decreased, and stabilized[1-5].

When the unit was started in cold state, the high-pressure cylinder was adopted as the starting mode, and the bypass system was a first-level high-pressure bypass. Before starting, the high-pressure cylinder was warmed up. Compared with the medium-pressure cylinder, the absolute expansion and relative
expansion difference of the high-pressure cylinder can meet the design requirements, but for the medium-pressure cylinder, the expansion was slow.

Refer to absolute expansion value of high pressure cylinder, intermediate pressure cylinder and low pressure cylinder and the relative expansion difference between the rotor when the unit was startup in cold state, it can been found that the expansion value of middle pressure cylinder thermal was only 0.6 mm when the unit speed was 1600 r/min and the unit was medium-speed warming, the expansion difference of middle pressure cylinder was 10.8 mm which exceeded the alarm value (-7.2 mm to 10.1mm). When the expansion difference increased, the stator component and rotor component of the medium pressure cylinder will produce dynamic and static expansion, resulting in a significant increase in the vibration value of NO.3 bearing bush, exceeding the alarm value.

3.2. Analysis of the causes of unsmooth expansion of medium pressure cylinder
When the unit was started in cold state, using high pressure cylinder starting, main steam entered into the high pressure cylinder at the turbine turns, high pressure cylinder exhaust temperature was low, because of the cold reheat steam, heat pipe was longer, was not fully warm tube, after the reheater into the intermediate pressure cylinder reheat steam temperature was low, intermediate pressure cylinder under the impact of the steam or cold water, cold cause warming cylinder inadequate of intermediate pressure cylinder expansion, affect the safe operation of the unit.

4. Troubleshooting measures and results achieved
The cold starting mode of the unit was optimized. By setting up the middle pressure cylinder starting system, the steam inlet of the middle pressure cylinder can be flushed, and the middle pressure cylinder can be heated fully and evenly.

When the unit was started in cold state, the medium pressure cylinder can be adopted. During the starting process, the metal temperature of the medium pressure cylinder can be raised to ensure smooth expansion of the medium pressure cylinder, and the difference in expansion of the medium pressure cylinder can ensure that it was within the design range, avoided the dynamic and static friction of the medium pressure cylinder, and ensured that the unit kept a good vibration level.

4.1. Set up the cold medium pressure cylinder starting system of the unit
Through theoretical analysis and research to determine the cold medium pressure cylinder starting node program, mainly including high pressure cylinder preheating, reheating cold section pipe heating, reheating hot section pipe heating, boiler ignition, medium pressure cylinder steam intake flushing, low speed warming, medium speed warming, rated speed running and grid-connected. The steam source for starting the medium pressure cylinder and pre-heating the high pressure cylinder came from the heating system of the adjacent machine. The specific steam flow was as follows:

1) adjacent machine cooling section—adjacent machine heating system—reheat cold section pipe—reheater—reheat the hot section of the pipe—intermediate pressure cylinder—low pressure cylinder—condenser.

2) adjacent machine cooling section—adjacent machine heating system—reheat cold section pipe—high pressure cylinder—high pressure steam pipe and drain pipe—condenser.

4.2. Determined the steam inlet parameters of the medium pressure cylinder and calculated and analyzed the steam flow required for starting the medium pressure cylinder
On the premise that the temperature difference between the bottom and top wall of the pipe in the reheating and cooling section, the wall temperature difference of the reheater pipe, the thermal expansion of the medium-pressure cylinder and the dilatancy difference of the medium-pressure cylinder were all reasonable, the steam parameters related to the pre-heating of the high-pressure cylinder and the pre-heating effect of the medium-pressure cylinder were comprehensively analyzed to determine the steam inlet parameters of the medium-pressure cylinder: the pressure was 0.35 – 0.6 MPa, the temperature was 165 – 353 °C, in order to meet the requirements of target.
Through theoretical research and analysis, according to the rotary inertia of turbine and generator rotors, NO.1 to NO.10 support bearings, thrust bearings and the power consumption and blast loss of the main oil pump provided by the turbine plant and the electric machine plant, the steam flow required for the start-up of the medium pressure cylinder was calculated.

Rotational inertia of turbo-generator shafts (including steam turbine and generator) was 9022.22kg.m/s², the impact lift rate was 100r/min, rated speed was 3000r/min, the blast loss at rated speed was 3386KW, thrust bearing power consumption was 103KW, the power consumption of the main oil pump driven by the spindle was 300KW. The power consumption of each bearing was shown in table 1.

Table 1. The power consumption of each bearing.

| Support bearing number | power consumption | Support bearing number | power consumption |
|------------------------|-------------------|------------------------|-------------------|
| 1                      | 96.6              | 6                      | 307.5             |
| 2                      | 206.6             | 7                      | 307.5             |
| 3                      | 258.8             | 8                      | 360.8             |
| 4                      | 276.2             | 9                      | 273               |
| 5                      | 307.5             | 10                     | 273               |

The vacuum of condenser measured in field test was -97KPa and the condenser temperature was 35℃.

Through calculation, the rotational moment of shafting was 15447.56N.m, overcoming the work consumed by the rotational inertia of the shafting was 4852.64KW, enthalpy of exhaust steam in low pressure cylinder was 2565.59KJ/Kg, enthalpy of exhaust steam in medium pressure cylinder was 3174.29KJ/Kg, steam flow required to start the medium pressure cylinder was 66.89t/h.

4.3. Field test verified the safety and economy of cold medium pressure cylinder startup

The starting of the medium pressure cylinder can ensure the safety of the unit operation, and the monitoring parameters were all within a reasonable range. High, medium and low pressure cylinders and high, medium and low pressure rotors were heated evenly and expanded smoothly.

Intermediate pressure cylinder starting rushed into steam all week, and the boiler hot flush, simultaneous heating process of pressure, medium and low pressure cylinder and rotor heating time was long, uniform heating, upper and lower half cylinder [difference was small, your poor little points inside and outside surface of the flange in the cylinder wall, re heater steam temperature and medium pressure cylinder metal temperature better match, at the same time warm high pressure cylinder continued investment at startup, high pressure and high pressure cylinder rotor temperature distribution; The high, medium and low pressure cylinders have little thermal impact, and reduce the thermal stress of the high, medium and low pressure rotors in the starting process, thus effectively extending the service life of the unit.

When the medium pressure cylinder was started, the blanking steam entered into the reheater through the reheating and cooling section pipeline of the adjacent machine heating system, and then entered into the medium pressure cylinder through the reheating and heating section pipeline for work, then entered into the condenser. Ensure that there was always steam flow in the reheater after the boiler ignition, and evenly heated the reheater pipe to avoid overheating of the reheater after the boiler ignition and extended the service life of the unit.

When the medium pressure cylinder started in cold state, the warm cylinder of the medium pressure cylinder was full and expanded smoothly, eliminating the static and dynamic friction. In the process of starting test, the vibration value of NO.3 bearing bush was always within a reasonable range, fundamentally eliminating the problem that the shaft vibration value was too large when the cold starting up, and improving the operation safety of the unit.

The vibration of each bearings was all meet the requirment of degine when the unit adopted medium pressure cylinder starting mode.
Cylinder thermal expansion, expansion difference and axial translation value were shown in Table 2.

**Table 2.** Cylinder thermal expansion, expansion difference and axial translation value. mm

| Time    | Speed rate/rpm | thermal expansion of high pressure cylinder | thermal expansion of medium pressure cylinder | axial translation | expansion difference of high pressure cylinder | expansion difference of medium pressure cylinder | expansion difference of low pressure cylinder |
|---------|----------------|--------------------------------------------|---------------------------------------------|-------------------|-----------------------------------------------|-----------------------------------------------|-----------------------------------------------|
| 15:02   | 0              | 13.713                                     | 5.601                                       | -0.579            | -1.437                                       | -3.075                                       | 9.238                                         |
| 15:08   | 321            | 13.713                                     | 5.601                                       | -0.455            | -1.437                                       | -3.075                                       | 8.736                                         |
| 15:13   | 571            | 14.464                                     | 5.601                                       | -0.431            | -1.437                                       | -3.075                                       | 8.736                                         |
| 15:16   | 702            | 13.933                                     | 5.601                                       | -0.404            | -1.437                                       | -3.075                                       | 8.736                                         |
| 15:53   | 1002           | 14.488                                     | 5.799                                       | -0.384            | -1.187                                       | -2.806                                       | 8.221                                         |
| 16:06   | 1208           | 14.488                                     | 5.799                                       | -0.361            | -1.187                                       | -2.806                                       | 8.221                                         |
| 16:13   | 1500           | 14.989                                     | 5.799                                       | -0.361            | -1.187                                       | -2.806                                       | 7.209                                         |
| 17:47   | 1500           | 17.082                                     | 6.699                                       | -0.439            | 0.298                                        | -3.881                                       | 9.718                                         |
| 17:48   | 1833           | 17.082                                     | 6.699                                       | -0.439            | 0.298                                        | -3.881                                       | 8.712                                         |
| 17:50   | 2115           | 17.082                                     | 6.699                                       | -0.439            | 0.298                                        | -3.881                                       | 8.194                                         |
| 17:52   | 2462           | 17.082                                     | 6.699                                       | -0.439            | 0.298                                        | -3.881                                       | 6.601                                         |
| 17:55   | 2852           | 17.082                                     | 6.699                                       | -0.439            | 0.298                                        | -3.881                                       | 5.008                                         |
| 17:58   | 3000           | 17.082                                     | 6.699                                       | -0.416            | 0.298                                        | -3.881                                       | 4.476                                         |

The normal range of differential expansion of high pressure cylinder was from -7.3mm to 13.5mm, and medium pressure cylinder was from -7.2mm to 10.1mm, low pressure cylinder was from -6.5mm to 32.6mm. The allowable value of axial translation was from -1.08mm to 0.6mm.

From table 2, it can be seen that all safety monitoring operating parameters were within the allowable range when the middle pressure cylinder was started.

Adjacent machine heating system will reheat cooling section of pipeline connection for two units, any unit cold startup can be provided by the adjacent machine steam, to warm and intermediate pressure cylinder of high pressure cylinder start, uniform heating medium pressure cylinder, the uniform expansion of cylinder and rotor, the vibration value to achieve a good level, to ensure the safe and stable operation of unit, eliminated the safe hidden trouble of equipment.

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