Analysis and treatment of vibration of 1000MW secondary reheat steam turbine with super-long single-support shafting

Kai Zhang[1], *Yongli* Zhao[1], and *Libo* Li[2, *]

[1]Datang Dongying Power Generation Co. Ltd,Dongying,China
[2]Datang Northeast Electric Power Test Research Institute Co. Ltd,Changchun, China

Abstract. In the context of new energy grid connection, thermal power units are gradually developing in the direction of large-scale and long-axis. However, due to the static deflection of the long shaft system, the rotor presents the shape of a lift curve during the installation process, which brings a huge challenge to the vibration stability of the rotor during operation. In addition, the shafting of the new million units in my country gradually takes the single support as the main support form, and the double support solution cannot be directly applied to the method of dealing with vibration excess. At the same time, there are few mature and complete technical solutions for reference in China. In this regard, this paper analyzes the vibration data and frequency spectrum of the generator during the commissioning of the No. 2 59.9 m ultra-long shafting unit in a factory , and finds that the vibration is caused by the thermal state generated by the generator rotor under load. unbalanced. Finally, after designing a targeted balance weight scheme and implementing it on site, the vibration of the generator bearing has reached an excellent level. This paper fills the vacancy of the vibration treatment of the ultra-long single-support shafting of the million-level units in China, and lays the foundation for the large-scale and long-shafted thermal power units.

Keywords: 1000MW, Secondary reheating, Rotor dynamic balance, Single-support shafting.

1 Introduction

The large-scale thermal power unit and the long shaft of the rotor are the current development trends. At the same time, with the continuous integration of new energy sources, it has brought new challenges to the safety and stability of high-power thermal power units [1] . Among them, the stability of the rotor shafting is the key to the stable operation of the unit. For the long shaft system, during the installation process, due to the static deflection due to its own weight, both ends of the rotor support point will generate a certain lift, and the rotor itself will also generate a smooth lift curve [2] ; at the same time, during the high-speed operation of the rotor, it is extremely sensitive to the parameter changes of the operating

* Corresponding author: 26081824@qq.com

environment, so it is extremely prone to the problem of rotor vibration exceeding the limit, affecting The normal operation of the unit is stable.

Most of the bearing support forms of China's new million-unit steam turbine generator sets are single support. Compared with the double-supported form, because only one end is supported, the other end is supported on the adjacent rotor through the coupling , which makes the vibration characteristics of the single-supported shafting steam turbine unit more complicated than that of the traditional double-supported unit[4] , which cannot be directly Apply the treatment plan of the double-supported rotor. At the same time, because the ultra-long single-support bearing will increase the difficulty of vibration analysis and rebalancing, the shafting vibration problem of the million-second reheat steam turbine in China is still in its infancy and exploration stage, and there are few mature and complete technical solutions available. for reference.

In this regard, this paper conducts fault diagnosis and corresponding treatment for the thermal vibration problem that occurs between the 59.5m super-long shafting of a million double reheat steam turbine. Finally, through the on-site dynamic balance counterweight, the vibration of each bearing pad of the generator reaches an excellent level.

2 Unit overview

Unit 2 of a power plant is a single-shaft six-cylinder six-exhaust ultra-supercritical intermediate double-reheat condensing steam turbine generator set produced by Shanghai Electric, with a total shaft length of about 59.5 m . This model is a million new units produced by the Shanghai Steam Turbine Factory with the introduction of Siemens technology. The shaft system of the unit is a single-support shaft system, which is the longest among the domestic million-level units.

2.1 Shafting composition

The steam turbine part of the steam turbine generator set is composed of a high pressure rotor (HP), an extra high pressure rotor (VHP), a medium pressure rotor (IP) and three low pressure rotors (LP1,LP2,LP3); the generator part is It consists of a water-hydrogen-hydrogen generator (GEN) and a static exciter (EXC) rotor. The generator rotor is a double support structure, and the excitation end of the exciter rotor is formed by a four-piece tilting pad bearing and the generator to form a three-support structure. The specific shafting arrangement is shown in Figure 1.

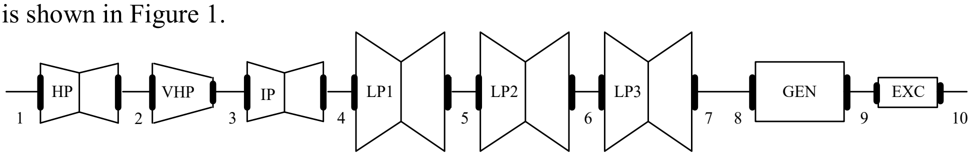

Fig. 1. Schematic diagram of shaft system.

2.2 Generator vibration

On September 25, 2020, Unit 1 ran for the first time.After constant speed, the amplitude values of each pad of the shaft system were within the excellent range. As the load increased, the vibration of the bearing pads on both sides of the generator rotor began to increase, especially the load When it reaches more than 450MW , the vibration of the generator bearing rises rapidly, and the final vibration amplitude reaches 140 μ m. When the load drops below 400MW , the vibration begins to drop. Looking at the vibration spectrum, the vibration of 8 watts and 9 watts is the same. Frequency doubling is the main factor, and the phase change is about 10 ° during the vibration change process . The vibration amplitude of the unit at the first constant speed is shown in Table 1.

Table 1. Vibration data at the first constant speed.

Measuring point	1X	2X	3X	4X	5X	6X	7X	8X	9X	10X
critical speed	40	26	58	77	42	51	19	35	55	53
Working speed	81	48	19	25	24	21	20	52	63	39

3 Analysis of abnormal vibration of single-support shaft system

According to the vibration phenomenon, it is judged that the generator rotor has a thermal imbalance fault. The specific analysis is as follows:

3.1 Cooling failure

The ventilation hole is the main air passage for cooling the generator rotor. If the ventilation hole is deformed for some reason, the flow area of the ventilation hole will be reduced, resulting in uneven cooling of the generator rotor locally and asymmetric temperature field of the rotor cross section. , and then cause thermal bending failure [5] . When a cooling fault occurs, as the temperature of cold hydrogen increases, the degree of asymmetric cooling of the generator rotor is relatively reduced, and the thermal imbalance vibration caused by the cooling fault is also reduced.

For verification, the temperature of cold hydrogen was changed during operation. With the change of temperature, the vibration amplitudes of generators 8 watts and 9 watts hardly changed. The test results proved that the vibration of generator bearings has no correlation with the temperature of cold hydrogen. , which can rule out generator cooling failures.

3.2 Short circuit between turns

Turn-to-turn short circuit is also one of the frequent failures of the turbine generator rotor. The main reasons are as follows: First , the winding is subjected to a huge centrifugal force during the start and stop of the unit, resulting in displacement, deformation and localization of the inter-turn insulation. Damage[6]; Second, due to the manufacturing process, the winding is not fixed firmly, the processing quality of the bar is poor, and the insulation between turns deviates, resulting in insulation damage.

There are many methods for diagnosing inter-turn short-circuit faults. Generally, methods such as AC impedance method, repetitive pulse method, and bipolar voltage balance method[7] are used for comprehensive diagnosis. Finally, through the dynamic test, the possibility of inter-turn short circuit in the unit was ruled out.

3.3 Poor expansion of the coil

The magnetic field of the generator is established by the excitation current of the rotor winding, the excitation current passes through the winding and heats the coil, and the coil expands to both ends after being heated[8] . The rotor parts of the generator are squeezed together due to the centrifugal force. Due to the different materials and temperatures of the parts, the expansion coefficients are also different, and there is relative expansion, resulting in friction on the contact surface. If the frictional force is asymmetric, a bending moment will be generated, which will bend the rotor [9] . This friction effect usually occurs between the coil and the slot wedge, and between the end coil and the inner surface of the grommet. For example, when the coil is heated and the expansion is hindered, an asymmetric axial force will be generated [10] . The thermal imbalance vibration caused by internal friction has the following characteristics: the vibration also increases with the increase of the excitation current. Even if the excitation current is reduced, the vibration does not recover immediately, and there is often a certain lag.

According to the vibration characteristics of the unit, the vibration of the generator has a certain corresponding relationship with the excitation current. Since the excitation current basically corresponds to the load trend, when the load increases to a certain value, the expansion of the coil is blocked, causing thermal bending, and when the load decreases, the coil shrinks, but the heat loss will have a process, resulting in a certain vibration recovery. lag. Therefore, it can be preliminarily determined that the poor expansion of the coil is the main reason for the vibration of the generator rotor.

4 Vibration treatment

According to the cause of the vibration fault, in order to eliminate the vibration of the generator rotor, it is necessary to analyze the mode shape of the generator-exciter system to determine which vibration treatment method to adopt.

4.1 Analysis of generator vibration mode

The generator rotor of this unit is a typical flexible rotor. The on-site balance of the flexible rotor usually adopts the modal balance method. According to the principle of the orthogonality of the mode shape, the vibration component of each order of the flexible rotor can only be caused by the unbalance of the corresponding order. If the unbalanced components of each vibration mode of the rotor are corrected, the vibration of the rotor will be in a better state.

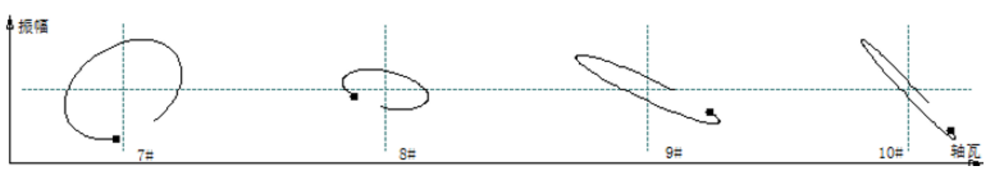

Fig. 2. Hologram of excitation system.

According to the holographic spectrum of the generator - exciter shafting at 3000r/min in Fig. 2 , the mode shape of the generator can be preliminarily judged, and the vibration of the generator is obviously affected by the third-order mode shape.

Usually, when balancing the response of the second-order mode shape, the antisymmetric weight can be added to the fan ring positions at both ends of the generator rotor [11] . For the third-order mode shape at the working speed, because there is no equipment in the middle of the generator rotor on site Therefore, only symmetrical weights can be added to the fan ring on both sides of the generator or the position of the wheel [12] . Due to the long period of dismantling the sealing tile, the commissioning progress of the unit is seriously affected. Finally, it was decided to align the wheels on both sides of the generator. position for dynamic balancing work.

At the first constant speed, the vibration Bode diagrams of generators with 8 watts and 9 watts are shown in Figures 3 and 4.

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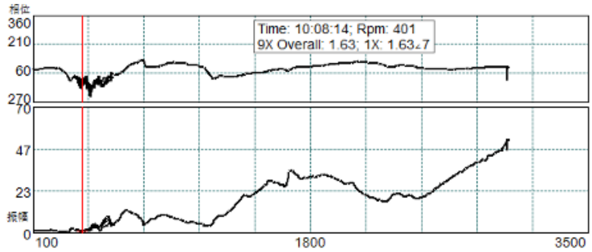

Fig. 3. Bode diagram of 8 watt liter speed.

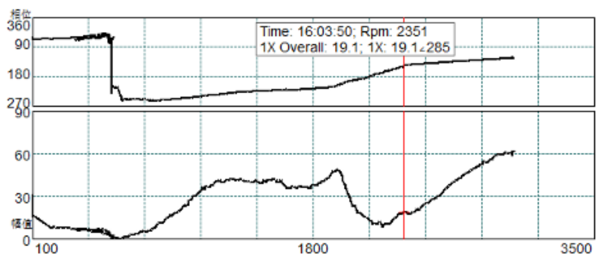

Fig. 4. Bode diagram of 9 watt liter speed.

4.2 Selection of emphasis plane

According to the third-order vibration mode of the generator[13], although the fan ring and the weighting of the intermediate position can effectively reduce the third-order vibration of the generator, it is very difficult to implement on-site. The weight can also effectively reduce the vibration of the generator rotor. But at the same time, the influence of the counterweight on the vibration of the low-voltage rotor and the rotor of the exciter should also be considered.

Fig. 5. The third-order vibration shape diagram of the generator.

10 watts where the exciter rotor is located is within 45 ° of the phase of the adjacent generator rotor , which is basically the same direction. Therefore, the counterweight to the wheel reduces the vibration of the generator and also reduces the vibration of the generator. Has a positive effect on the vibration of adjacent bearing pads and does not worsen existing vibration levels. If you want to eliminate the vibration of the generator rotor by means of on-site dynamic balancing in a short time, the best solution can only be to dynamically balance the wheels on both sides of the generator.

4.3 Dynamic balance effect

According to the on-site dynamic balancing experience of millions of single-support shaft systems, the dynamic balancing scheme is determined as follows: the low-voltage side of the generator weighs 900 g on the wheel, and the excitation side of the generator weighs 1 000 g on the wheel.

Table 2. Vibration data at 450MW (before dynamic balancing).

Measuring point	6X	7X	8X	9X	10X
3000r/min	36/354	44/140	116/145	136/123	55/124

When the unit starts again after the counterweight, the vibration amplitude at the first-order critical speed of the generator increases by about 30 μm compared with the first start , but the maximum value does not exceed 120 μm. With a load of 450MW , the maximum vibration amplitude of the generator does not exceed 90 μm, and the vibration amplitudes of the adjacent low-voltage rotor of 7 watts and the exciter of 10 watts are reduced by 10 μm and 8 μm , respectively. According to the relevant requirements of GB/T11348.2 , the shafting vibration of this unit is at an excellent level, and the vibration after loading is shown in Table 3.

Table 3. Vibration data at 455MW (after dynamic balancing).

Measuring point	6X	7X	8X	9X	10X
3 000r/min	37/3	33/122	63/140	86/103	47/120

5 Conclusion

In this paper, the vibration problems of a million-level double reheat steam turbine generator set in China are analyzed and dealt with accordingly, and the conclusions are as follows:

1) In this paper, through the elimination method and experimental verification, it is found that the root cause of generator vibration is thermal imbalance. When dealing with the thermal imbalance problem, it can be confirmed according to the phenomenon of vibration;

2) For a single-support shaft system, the vibration phase of the bearing pads on both sides of the opposite wheel should be basically in the same direction. To avoid the problem of increased vibration, it is necessary to ensure that the phase difference should not exceed 45 ° .

3) This paper solves the vibration problem of the longest single-support shaft system of the million-level unit through practical cases, fills the corresponding vacancy, and provides reference and reference for the handling of similar faults in the future .

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