Analysis and Treatment of a Large Abnormal Vibration of 10 Watts in a 1000 MW Generator due to the Deformation of the Rotor End Winding

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Abstract. With the widespread application of large-capacity and high-parameter generators in the field of coal-fired power generation, there are more and more cases in which the vibration at both ends of the generator increases abnormally with load changes. This article introduces in detail the analysis and treatment process of the abnormal continuous increase of the 10-watt vibration of a 1000MW turbo-generator after it has been put into operation for two years. After the rotor returned to the factory for disassembly and overhaul, it was finally confirmed that the stacking of the full-size insulating tiles under the guard ring caused partial blockage of the winding deformation of the rotor end and the ventilation holes were the direct causes of abnormal vibration of the generator.

1. Introduction

As the core equipment of power plants, steam turbine generator sets are large-scale high-speed rotating machinery with rotor systems as the main body. They play a very important role in electric power, petrochemical, metallurgical and other industries. Vibration faults are the most common faults in the operation of steam turbine generators[1]. When the vibration of the generator sets exceeds the limit, it will affect the stable operation of the generators. In severe cases, it may even lead to disastrous consequences[2]. Therefore, vibration is the most important indicator to measure the safety and reliability of the unit, and it is also a comprehensive reflection of the level of unit design and manufacturing, installation and maintenance, and operation and maintenance. Shaft vibration is inevitable during the commissioning and operation of the turbo-generator set[3].

In recent years, my country's power industry has developed rapidly, the structure of the power industry has been continuously adjusted, and advanced large-scale turbo-generator units have been put into operation one after another. With the development of large-scale and high-parameter units, the structure of the unit has become more and more complex, and the shaft system has become longer and longer[4]. At the same time, in order to reduce leakage and pursue high efficiency, the gap between dynamic and static components is also designed to be relatively small, which makes the unit more prone to shaft vibration failure during commissioning and operation.[5].

The No.3 generator of a power plant is a QFSN-1000-2 three-phase synchronous turbo-generator produced by Harbin Electric Group, which adopts self-shunt excitation static excitation and water-hydrogen-hydrogen cooling. The generator bearing is an elliptical tile bearing with a single flow ring seal. In November 2009, it passed the 168-hour test run, and all operating parameters of the unit were normal.
In April 2011, the power plant's No. 3 unit experienced an abnormal increase in vibration with load during operation, and the maximum axis vibration in the 10Y direction reached 90 μm. Subsequently, in the process of the No. 3 unit lifting and lowering the load many times, the phenomenon of the generator 10Y-direction shaft vibration slowly climbing with the load repeated many times. Over the years, many on-site diagnosis, analysis and dynamic balance tests have been carried out, and the problem of vibration of Unit 3 climbing with load and time has not been fundamentally solved. The shafting structure of the power plant's No. 3 turbo-generator set is shown in Figure 1.

Figure 1. Shafting structure diagram of generator set.

2. Abnormal Vibration Characteristics
In order to analyze the vibration characteristics and its changing laws, the experiments of variable hydrogen temperature, variable oil temperature, variable water temperature and sandbags were carried out on Unit 3 without affecting the operation of the unit. Under stable load, there is no obvious change in the 10-watt shaft vibration and the bush vibration. Based on technical data such as generator rotor vibration changes with load, rotor vibration analysis report, rotor turn-to-turn short circuit diagnosis analysis report, dynamic balance test and other technical data, the main problems of generator No. 3 vibration are summarized as follows:

1. The ratio of 10-watt bearing vibration to shaft vibration is obviously higher.

2. Vibration changes greatly with load, and the maximum vibration change from no-load to full-load exceeds 50μm.

3. When the load is below 800MW, the vibration changes little; when the load is greater than 800MW to close to full load, the vibration value continues to increase.

4. The running time of the random group with the maximum value of 10 watt vibration gradually increases.

5. The aggravation angle of the dynamic balance is basically the same in all previous times.

6. In the absence of maintenance and dynamic balance treatment, after shutdown and restart, the vibration is relatively reduced under the same load, but it gradually increases with the running time.

7. After the dynamic balance treatment, the basic vibration can drop in a short time, but as the running time increases, the vibration gradually recovers or exceeds the previous high value.

8. The vibration conditions of 10W at 400MW and 1000MW are shown in Table 1 below.

| Location | 400MW Pass frequency/one octave frequency/phase (μm/μm/°) | 1000MW Pass frequency/one octave frequency/phase (μm/μm/°) |
|----------|----------------------------------------------------------|----------------------------------------------------------|
| 9X       | 20/14/60                                                 | 28/22/165                                                |
| 9Y       | 36/32/302                                                | 43/35/65                                                 |
| 10X      | 21/20/223                                                | 48/47/212                                                |
| 10Y      | 50/47/76                                                 | 108/105/87                                               |
| 9B       | 32/31/152                                                | 30/29/192                                                |
Based on the analysis and discussion of the main manifestations of generator vibration and related data, the main conclusions are as follows:

1. There are two main reasons that may cause the 10 watt generator to vibrate: one is the weak dynamic rigidity of the generator bearing seat, foundation and other structures, and the other is the thermal bending of the generator rotor[6].

2. The reasons for the relatively weak dynamic rigidity of the generator's bearing seat, foundation, etc. may include uneven load distribution on the stator foot of the generator, poor contact between the bearing and bearing ring, loosening of the generator base plate, and cracking of the secondary grouting of the foundation, etc.

3. Thermal bending of the generator rotor may be caused by the blockage of the rotor ventilation holes, the obstruction of the sliding of the spacer under the rotor winding wedge, the deformation of the winding and the loosening and displacement of the end insulating spacer[7].

4. The weak dynamic stiffness of the generator bearing seat, foundation and other structures is the main reason for the large generator bush vibration and the super high ratio of bush vibration/Shaft vibration.

5. According to the diagnostic test results of several generator rotor winding turn-to-turn insulation conditions carried out from 2015 to 2018, it is believed that there is no short-circuit fault between the rotor winding turns.

3. Return to Factory Repair Process

In order to find out the abnormal cause of the large 10 watt vibration of the No. 3 generator, and completely solve the unit load reduction or non-stop event caused by the high vibration, after multi-party consultation, it was decided to combine the No. 3 unit B repair and return the rotor to the factory for inspection and maintenance work.

A preliminary inspection of the end windings was carried out through an endoscope, and it was found that the two ends of the steam excitation were loose. After negotiation, it was decided to open the rotor steam end and excitation end retaining ring, and check whether the rotor end winding was deformed and the end insulating pad was displaced.

After opening the rotor guard ring, it was found that multiple insulating pads at the end were loosened and peeled off and the end winding of the rotor was deformed seriously. The top turn winding of the rotor No. 4-No. 8 had obvious deformation caused by squeezing. The position of the winding deformation is mainly concentrated at the gap between the edge of the rotor damping ring and the outer insulating tile of the guard ring, as shown in Figure 2.
Figure 2. The winding at the end of the rotor is deformed due to squeezing.

After inspecting the insulating tile on the outer layer of the guard ring after disassembly, it is found that there are many protrusions caused by overlapping folds at its edges. Observing the insulation of the removed guard ring, it can be seen that at the intersection of the damping ring and the outer full-size insulating tile of the guard ring, the outer insulating tile has obvious wrinkles and bumps; the inner full-size insulating tile of the corresponding part has the obvious dent is about 1 cm deep, as shown in Figure 3.

Figure 3. the outer full-size insulating tile.

After the rotor coil is lifted out, the deformation of the coil and the blockage of the air duct are shown in Figure 4.
Later, according to the inspection of the rotor end windings, it was decided to lift all the rotor coils out and send them to the coil factory for grinding, cleaning, shaping and pasting the inter-turn insulation paper (the part in the slot). In accordance with the negotiated maintenance plan, it was decided to replace the top-turn windings of the rotor No. 1 to No. 8 coils, and to polish, clean and reshape the other windings. After the winding shaping was completed, the end winding of the rotor coil was welded and offline installation work was carried out, and the rotor was sent to the heating furnace (heating time 24h) to carry out the overall heating and drying of the rotor winding. Drying and grinding rotor coil shaped case shown in Figure 5.

Witnessed by many parties, the rotor has carried out various electrical tests before and after the dynamic balance. The test content includes the insulation resistance, DC resistance, two-pole voltage balance test, AC withstand voltage test, air tightness test, and rotor ventilation test. The results all meet the requirements of relevant standards and are qualified.

4. Analysis and Treatment of Abnormal Vibration
The use of sections to divide the text of the paper is optional and left as a decision for the author. Where the author wishes to divide the paper into sections the formatting shown in table 2 should be used.

The end of the rotor winding is mainly composed of a guard ring, a center ring, a damping ring, and a guard ring insulation tile. Its structure is shown in Figure 10. According to the actual assembly situation of the rotor end winding after repair, the drawn rotor assembly schematic diagram is shown in Figure 6.
As shown in Figure 7, the main structure of the end of this type of rotor winding is (from the outside to the inside): guard ring, damping ring, lower half-size insulating tile of damping ring, outer full-size insulating tile, middle polyimide Amine film and inner full-size insulating tiles. The damping ring is comb-shaped. One end of the tooth is connected to the end of the rotor pole shoe deep into the slot wedge, and there is a toothed insulating plate at the bottom; the other end is a short-circuit copper ring, and the bottom is supported by a half-size insulating tile. The insulation at the bottom of the guard ring is mainly composed of two layers of full-size insulating tiles and a layer of polyimide film in the middle[8].

According to the site inspection, the actual assembly drawings of the generator and the installation of the repaired rotor end winding guard ring and insulation tile, it is believed that the direct cause of the deformation of the top turn winding at the rotor coil end is the lower outer layer of the guard ring. The full-size insulation tiles are piled up. The root cause of the pile up of full-size insulation tiles under the guard ring is due to the irregular size and shape of the rotor coil processing and end winding assembly. The end of the coil before the heat sleeve guard ring is not shaped properly, resulting in the deviation of the outer diameter of the coil. When the guard ring is heated, the gap between the guard ring and the insulating tile of the guard ring is too small. When the guard ring heat jacket advances, the full-size insulating tile under the guard ring under the influence of the high temperature of the guard ring heat jacket will be scraped and an insulating layer will occur. The phenomenon of accumulation. Under the background of long-term operation of the unit, the combined effect of centrifugal force and thermal stress causes the top-turn windings and end coils of the rotor where the insulating tiles are piled up to deform and the deformation range gradually expands.

Because the top turn coil of the rotor end winding is composed of two copper bars with a thickness of 6.75mm, the copper bars are milled with a through hydrogen cooling air duct. Therefore, when the
generator is operating normally, the outer insulation is in the guard ring. The insulating tiles are hung up during the heating process to cause wrinkles and bulges. Under the action of strong centrifugal force, the unsupported air passage inside the top turn coil is first squashed and deformed. The 2-7-turn coil of the rotor is made of a copper bar with a thickness of 13.5mm. Although there are also ventilation channels inside, the pressure resistance is greater than that of the top-turn coil, so the deformation range is smaller. For the bottom turn coil, its structure is the same as that of the top turn, but because it is at the lowest end and affected by the 2-7 turns of the coil, the deformation amplitude is also smaller[9,10].

In order to solve the problem of squeezing and deformation of the coil at the end of the rotor and do a good job of preventing the problem of the rotor, the measures taken are as follows:a)Replace the top-turn windings of all the rotor coils and perform grinding and shaping work on other coils; b)Strengthen the coil ends The outer diameter of the coil end before the thermal sleeve retaining ring must be reshaped to the specified size (design value +6mm), and the outer diameter size must be strictly checked whether it meets the requirements; c)After the thermal sleeve retaining ring, check the coil end with an endoscope Whether the top-turn winding is squeezed or deformed, re-examine it with an endoscope after the dynamic balance is over-speeded to ensure that the reworked rotor no longer has the same problem.

5. Conclusions

In order to prevent the occurrence of similar types of failures and ensure the safe and stable operation of power plant generator sets, it is recommended that the following work be carried out in the future:

1) Before the No. 3 generator set is put into operation, according to the requirements of relevant standards, the relevant electrical preventive tests and the evaluation of the inter-turn insulation status after the rotor repair shall be carried out in time.

2) During the impulse rotation and speed increase, grid connection, and load operation of Unit 3, the impulse rotation parameters and vibration data are monitored throughout the whole process, focusing on the vibration changes of the generator from no load to full load, and maintenance Compare the previous vibration data.

3) Strengthen the operation and monitoring of No. 4 units of the same type and batch, and focus on the changes in the 9W and 10W vibrations of No. 4 units. Once the vibration becomes abnormally large, the cause should be found in time.

4) In time with the opportunity of shutdown and maintenance of No. 4 unit, use an endoscope to carefully check the deformation of the end winding of the No. 4 generator rotor, focusing on whether there is any deformation of the top turn winding and whether there is looseness of the end cross-axis spacer. And take corresponding measures in time according to the inspection results.

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