Analysis of typical problems in stator core magnetization test of turbine generator

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Abstract. The basic principle of turbogenerator stator core magnetization test is introduced, aiming at the overheated condition of stator core during magnetization test of No.1 generator in Yingkou Power Plant of Huaneng International Electric Power Co., Ltd., the causes of hot spots in the core during the test are analyzed, the test, inspection and treatment process are introduced, after treatment, the stator core of the generator can be operated.

Keywords: generator, stator core, magnetization test.

1. Introduction
With the increasing number of large-scale units put into operation, the operation time is increasing year by year, and some units are gradually aging. Stator core is one of the core parts of generator, as a result of long-term operation, causes the poor insulation between silicon steel sheets of core, which will cause great hidden danger to the safe and stable operation of the unit.

The stator core of generator is composed of silicon steel sheets, after long-time operation of generator, due to the large magnetic flux leakage at the end, the vibration at the end is relatively large, long term vibration makes core lamination loose locally, cause the vibration of the iron core between pieces, gradually damage the insulation between pieces, local eddy current loss increases, local overheating will occur [1]. No.1 generator of Yingkou Power Plant of Huaneng International Electric Power Co., Ltd. was put into operation in 1995, in 2018, the magnetization test of generator stator core was carried out during unit overhaul, and it was found that the core was over hot, test again after treatment, Overheating at this point still exists. Through analysis, it is determined that the fault point is located at the deeper position of stator core, remove the stator coil related to the core over hot spot, after treatment, it is verified by the magnetization test of generator stator core, ensure the stable operation of the unit.

2. Basic principle of magnetization test of generator stator core
The magnetization test of generator stator core mainly uses the principle of no-load operation of transformer, take the stator core of the generator as the flux loop and wind the excitation winding as the primary side, AC current in the winding, to produce an alternating flux close to the saturation state
in the core and magnetize the core, thus, eddy current and hysteresis loss are generated in the iron core, heat the iron core, there will be large eddy current in the damaged or deteriorated part of the insulation between pieces in the core, rapid temperature rise [2]. Wrap the secondary side at 90 ° with the original side, connect the corresponding meter at the secondary side (voltmeter, ammeter, low power factor wattmeter). Using infrared thermal imager to monitor whether the stator core of generator has over hot spot, according to GB / T 20835-2016 guide for magnetization test of generator stator core, at the specified flux density, after the specified time of test, maximum temperature rise limit of 50Hz / 60Hz generator core is less than or equal to 25K, the temperature difference limit of the same part (stator tooth or slot) of 50Hz / 60Hz generator is less than or equal to 15K [3]. The diagram of magnetization test of generator stator core is as follows.

Figure 1. The schematic diagram of magnetization test of generator stator core is as follows.

In the picture: 1—Stator core of generator; 2—Excitation winding; 3—Measuring winding; S—AC power supply; TA—Current transformer; A—AC ammeter; V—AC voltmeter; W—Low power factor wattmeter; D1—Outer diameter of stator core; D2—Inner diameter of stator core; hys—Stator core yoke high; hs—Stator tooth height.

3. Calculation of generator stator core magnetization test
Before the test, the relevant dimension parameters of generator and GB/T 20835-2016 guide for magnetization test of generator stator core shall be followed, calculation of the numbers of excitation winding in generator stator core magnetization test, make the magnetic flux reach 1.4T during the test, close to the normal operation flux of generator, test time 45 minutes. If the flux density does not reach 1.4T in the test, it can be converted according to 6.4.1.2 of GB / T 20835-2016 guide for magnetization test of generator stator core, determine the test time.

Calculation of relevant parameters:
The net length of stator core is determined by the following formula:
In formula: \( k_{Fe} \) — Lamination coefficient of stator core, normally. When the thickness of silicon steel sheet is 0.35mm: \( k_{Fe} \) value range: 0.93-0.96; When the thickness of silicon steel sheet is 0.50mm: \( k_{Fe} \) value range: 0.94-0.97.

\[ l = k_{Fe}(l - b_v n_v) \]  

(1)

The height of stator core yoke is determined by the following formula:

\[ h_{ys} = \frac{(D_1 - D_2)}{2} - h_{e} \]  

(2)

The sectional area of stator core yoke is determined by the following formula:

\[ Q = l_a h_{ys} \]  

(3)

The number of excitation coil turns is determined by the following formula:

\[ W_1 = \frac{U_1}{4.44fQB} \]  

(4)

In formula:

\( U_1 \) — Excitation coil voltage, from auxiliary power, V;

\( f \) — Test power frequency (Voltage frequency of excitation coil), Hz;

\( B \) — Flux density of stator core during test, T.

When the magnetic flux density does not reach 1.4T, the test time is determined by the following formula:

\[ t = \frac{(1.4/B)^2 \times 45}{1000} \]  

(5)

4. Typical case analysis

Main technical parameters of No.1 generator of Yingkou Power Plant of Huaneng International Power Co., Ltd. are shown in Table 1.

| Number | Item                        | Parameters                      |
|--------|-----------------------------|---------------------------------|
| 1      | Generator model             | TBB-320-2EY3 turbine generator  |
| 2      | Manufacturer                | Leningrad motor manufacturing company |
| 3      | Rated capacity              | 376MVA                          |
| 4      | Rated power                 | 320MW                           |
| 5      | Rated voltage               | 20kV                            |
| 6      | Rated current               | 10870A                          |
| 7      | Power factor                | 0.85                            |
| 8      | Rated speed                 | 3000r/min                       |
| 9      | Rated frequency             | 50Hz                            |
| 10     | Stator core length          | 4.6m                            |
| 11     | Stator vent width           | 0.005m                          |
| 12     | Numbers of stator vent      | 105                             |
| 13     | Outer diameter of stator core | 2.47m                         |
| 14     | Inner diameter of stator core | 1.225m                         |
| 15     | Stator tooth depth          | 0.211m                          |
Note: The service bus voltage of No.1 generator in Yingkou Power Plant of Huaneng International Power Co., Ltd. is 6300V.

Calculated from the generator parameters in Table 1 and formula (1), formula (2), formula (3) and formula (4), it can be concluded that: the net length of stator core of the machine is 3.79m, stator core yoke height 0.41m, the cross section area of stator core yoke is 1.56 square meters, the number of turns of excitation coil is 13.

4.1. Magnetization test of stator core

The magnetization test data of stator core of No.1 generator in Yingkou Power Plant of Huaneng International Power Co., Ltd. is shown in Table 2, Table 3 and Figure 2.

| Numble | Excitation coil voltage (V) | Excitation current (A) | Power loss (kW) | Frequency (Hz) | Magnetic flux density (T) |
|--------|-----------------------------|------------------------|-----------------|---------------|--------------------------|
| 1      | 6240                        | 336                    | 321.36          | 50.00         | 1.26                     |
| 2      | 6240                        | 345                    | 324.48          | 50.02         | 1.26                     |
| 3      | 6240                        | 351                    | 326.04          | 50.00         | 1.26                     |
| 4      | 6240                        | 351                    | 327.60          | 50.00         | 1.26                     |
| 5      | 6240                        | 354                    | 330.72          | 50.02         | 1.26                     |
| 6      | 6240                        | 360                    | 333.84          | 49.97         | 1.26                     |

Note: (1) Initial temperature: Excitation side 26.8℃; Central section 27.4℃; Turbine side 26.9℃; End temperature: Excitation side 35.9℃; Central section 34.2℃; Turbine side 32.8℃; (2) The magnetic flux density during the test is 1.26T, according to formula (5), the test time is 55 minutes.

| Numble | Generator 1 | Position of core teeth | Axial position of stator core | Temperature(℃) | Remarks |
|--------|-------------|------------------------|-------------------------------|----------------|---------|
| 1      | Excitation side | Between 32 and 33 grooves | paragraph 1                  | 137.0          | See Figure 2 |

Figure 2. Temperature between 32 and 33 grooves on excitation side (axial section 1 of core).

It can be seen from Table 2, Table 3 and Figure 2, the highest temperature of stator core magnetization test of No.1 generator in Yingkou Power Plant of Huaneng International Power Co., Ltd. is 137 ℃, located between 32 and 33 grooves on excitation side (axial section 1 of core), the
temperature rise at this point is 110.2K, temperature difference 101.1K, temperature rise and temperature difference do not meet the relevant requirements of 7.1 and 7.2 of GB / T 20835-2016 guide for magnetization test of generator stator core, that is, the maximum temperature rise limit is less than or equal to 25K, temperature difference limit less than or equal to 15K. The temperature rise of stator core is an important performance index of generator, controlling the temperature rise of stator core plays a key role in the load of generator [4].

It can be seen from the test results, the short circuit between the core laminations is serious, it is difficult to ensure the stable operation of the unit. In order to increase the insulation between laminations, the hot spot was treated by inserting mica between laminations. Due to long time running, the stator core has certain aging, during the treatment, a hot core lamination was found to have fallen off, see Figure 3.

![Figure 3. Broken core lamination.](image)

4.2. Conduct magnetization test of generator stator core again after treatment

The electrical data of the second stator core magnetization test is consistent with that of the first test (as shown in Table 2). For the first test overheat position, the whole process of real-time temperature monitoring is carried out in this test, relevant data are shown in Table 4, Figure 4-Figure 9.

| Table 4. Temperature data of stator core magnetization test (the second time). |
|--------------------------------|--------------------------------|-----------------|-----------------|-----------------|-----------------|
| Numble | Generator 1 | Position of core teeth | Axial position of stator core | Time | Temperature(℃) | Remarks |
| 1 | Excitation side | Between 32 and 33 grooves | paragraph 1 | 0:00 | 45.5 | See Figure 4 |
| | | | | 10:00 | 54.5 | See Figure 5 |
| | | | | 20:00 | 63.5 | See Figure 6 |
| | | | | 30:00 | 77.7 | See Figure 7 |
| | | | | 45:00 | 90.2 | See Figure 8 |
| | | | | 55:00 | 94.3 | See Figure 9 |

Note: Initial temperature: Excitation side 27.5℃; Central section 27.8℃; Turbine side 26.8℃;
End temperature: Excitation side 36.4℃; Central section 35.5℃; Turbine side 33.2℃.
It can be seen from Table 3, Table 4 and Figure 9, after processing, the maximum temperature between 32 and 33 grooves on excitation side (axial section 1 of core) is 94.3 °C, temperature rise 66.8K, temperature difference 57.9K, compared with the first test, the maximum temperature, temperature rise and temperature difference all decreased to a certain extent, however, it still does not meet the relevant requirements of 7.1 and 7.2 of GB / T 20835-2016 guide for magnetization test of generator stator core.

After analysis, when the infrared thermal imager is used to monitor the stator core in the test, only the surface temperature can be monitored, unable to monitor the temperature in the core depth, during the test, the temperature of the hot spot keeps rising (see Table 4, Figure 4-Figure 9), up to the end of the test, the balance and stability are not achieved, therefore, it can be determined that the bad insulation position between silicon steel sheets of stator core should be located in the lower layer of core between slots 32 and 33 (axial section 1 of core) on the excitation side. Therefore, the treatment method of inserting mica sheet on the surface of the core can not increase the insulation between sheets, to solve this problem, the stator coil associated with this hot spot location shall be removed, and insert the mica sheet into the lower core.

4.3. Magnetization test of stator core after treatment of lower core

The magnetization test results of the stator core after treatment of the lower core are shown in Table 5, see Table 6 for the temperature monitoring of the whole process of the test between 32 and 33 grooves on the excitation side (axial section 1 of the core), the temperature of this point is compared with that of the second test, see Figure 10.
Table 5. Electrical data of stator core magnetization test (the third time).

| Numble | Time  | Excitation coil voltage (V) | Excitation current (A) | Power loss (kW) | Frequency (Hz) | Magnetic flux density (T) |
|--------|-------|----------------------------|------------------------|-----------------|----------------|--------------------------|
| 1      | 0:00  | 6188                       | 337.10                 | 324.38          | 50.00          | 1.23                     |
| 2      | 10:00 | 6188                       | 337.18                 | 324.38          | 50.00          | 1.23                     |
| 3      | 20:00 | 6188                       | 337.22                 | 334.38          | 50.00          | 1.23                     |
| 4      | 30:00 | 6188                       | 337.40                 | 331.00          | 50.00          | 1.23                     |
| 5      | 45:00 | 6188                       | 337.40                 | 331.00          | 50.00          | 1.23                     |
| 6      | 55:00 | 6188                       | 337.47                 | 332.33          | 50.00          | 1.23                     |

Table 6. Temperature data of stator core magnetization test (the third time).

| Numble | Generator  | Position of core teeth | Axial position of stator core | Time | Temperature(℃) | Low point of temperature in the same circle(℃) |
|--------|------------|------------------------|--------------------------------|------|----------------|-----------------------------------------------|
| 1      | Excitation side | Between 32 and 33 grooves | paragraph 1                     | 0:00 | 36.1           | 36.1                                          |
|        |             |                        |                                | 10:00| 45.0           | 37.3                                          |
|        |             |                        |                                | 20:00| 50.3           | 38.6                                          |
|        |             |                        |                                | 30:00| 55.9           | 39.8                                          |
|        |             |                        |                                | 45:00| 60.0           | 41.0                                          |
|        |             |                        |                                | 55:00| 61.2           | 42.6                                          |

Figure 10. Comparison of core temperature.

It can be seen from Table 6 and Figure 10, After treatment of the lower core of the hot spot, the temperature of the core between 32 and 33 grooves (axial section 1 of the core) on the excitation side has been significantly improved, at the end of the test, the temperature at this point is 61.2 ℃, temperature rise 25.1K, temperature difference 18.6K, the temperature at this point has reached equilibrium and stable state within 10 minutes before the end of the test, no sign of continuous rise. According to the operation life of the unit and the iron core condition after this test, it is determined that the core of the unit can operate normally in one overhaul cycle. In the past two years of operation, no abnormality found in core temperature of the unit, it shows that the treatment effect is good, feasible treatment method. It is recommended to carry out key inspection on the iron core in the next overhaul.
5. Concluding remarks

5.1. Selection of excitation cable
Attention should be paid to the selection of excitation cable in the test preparation stage, because the cable needs to be wrapped on the generator body during the test, so the insulation strength of the cable must be good. Good current carrying capacity of cable, quick heat dissipation, convenient for winding on the generator body. Cable laying for mobile, frequent disassembly and assembly, cable insulation, sheath and conductor shall have corresponding mechanical strength [5]. The excitation cable shall be kept at a sufficient distance from the magnetic conducting metal parts such as the foot frame and iron plate around the generator or separated by wood plate, prevent the relevant metal parts from overheating due to the magnetic flux produced by the excitation cable during the test.

5.2. Judgment of temperature rise
If the temperature of a certain point of stator core increases with time during the test, and until the end of the test, the temperature at this point has not reached equilibrium and stable state, it can be basically judged that there is poor insulation in the lower layer of the core at this point, the stator coil corresponding to the over hot spot shall be removed, handle the poor insulation position of the lower layer, and retest for verification.

5.3. Points for attention in multiple tests
Because this test will generate a lot of heat inside the core, if it is necessary to conduct continuous stator core magnetization test for the same generator, the retest shall be conducted after the temperature of the stator core of the tested unit drops to room temperature, to ensure the accuracy of test data.

5.4. Introduction of mica
Mica is a silicate mineral crystal, can be peeled into thin slices, good electrical performance, heat resistance, fire resistance and chemical stability, good mechanical properties, little water absorption; Thin mica is soft and elastic, Very good corona resistance, it is very suitable for the treatment of bad insulation between silicon steel sheets of generator stator core.

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