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Test procedures for three-phase permanent magnet synchronous machines

三相永磁同步电动机试验方法

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Test procedures for three-phase permanent magnet synchronous machines

1 Scope

This Standard specifies the test procedures for three-phase permanent magnet synchronous machines.

This Standard is applicable to self-starting three-phase permanent magnet synchronous machines. The test for synchronous machines powered by static variable frequency power supply may refer to use. It is not applicable to synchronous machines with DC excitation winding.

2 Normative references

The provisions in following documents become the provisions of this Standard through reference in this Standard. For dated references, the subsequent amendments (excluding corrigendum) or revisions do not apply to this Standard, however, parties who reach an agreement based on this Standard are encouraged to study if the latest versions of these documents are applicable. For undated references, the latest edition of the referenced document applies.

GB 755-2008, *Rotating Electrical Machines - Rating and Performance* (IEC 60034-1:2004, IDT)

GB/T 1029-2005, *Test procedures for three-phase synchronous machines*

GB/T 1032-2005, *Test procedures for three-phase induction motors*

GB 10068-2008, *Mechanical vibration of certain machines with shaft heights 56 mm and higher-measurement evaluation and limits of vibration severity* (IEC 60034-14:2003, IDT)

GB/T 10069.1-2006, *Measurement of airborne noise emitted by rotating electrical machines and the noise limits - Part 1: Method for the measurement of airborne noise emitted by rotating electrical machines* (ISO 1680:1999, MOD)

GB/T 13958-2008, *Test procedures for non-direct current excitation winding synchronous motor*

P_{S0} - No-load stray loss (W);

P_0 - No-load input power (W);

P_K - Input power during stall (W);

P_{cu1} - I^2R loss of stator winding at test temperature (W);

P_{0cu1} - I^2R loss of stator winding under test temperature at no load (W);

P_{cu1S} - I^2R loss of stator winding at specified temperature (θ_s), (W);

R_1 - Initial resistance of the stator winding at a temperature of θ_1 (Ω);

R_N - End resistance of stator winding at the end of rated load thermal test (Ω);

R_t - Measured (or obtained) resistance of the stator winding end at the test temperature (Ω);

R_S - Stator winding end resistance (Ω) converted to a specified temperature (θ_s);

R_0 - Stator winding end resistance of no-load test (each voltage point) (Ω);

T_d - Torque reading (N·m);

T_{d0} - No-load (connected to the dynamometer) torque reading (N·m);

T - Corrected torque (N·m);

T_K - Torque at stall (N·m);

T_{p0} - Out-of-step torque measured under the test voltage U_T (N·M);

T_{p0N} - Out-of-step torque at rated voltage (N·m);

T_{min} - Minimum torque (N·m);

T_{pi} - Pull-in torque measured at test voltage U_t (N·m);

T_{piN} - Nominal pull-in torque at rated voltage (N·m);

T_a - Asynchronous torque (N·m);

T_N - Permanent magnet braking torque (N·m);

U - Terminal voltage (V);

U_0 - No-load test terminal voltage (V);

U_K - Stalling test terminal voltage (V);

4.1.2.2 Frequency stability

No rapid changes in frequency are allowed during the test because the rapid frequency change affects not only the motor under test, but also the output measurement device. The frequency change during the measurement shall be less than 0.1%.

4.2 Measuring instrument

4.2.1 Overview

The accuracy level of most instruments is usually expressed as a percentage of full scale. Therefore, try to select low-range meters according to the actual reading needs.

Factors that affect the accuracy of instrument measurement results:

a) Signal source load;

b) Lead wire correction;

c) Instrument range, operating conditions and calibration.

4.2.2 Electricity measuring instrument

In general, the accuracy of electricity measuring instruments shall not be less than 0.5 (full scale, except megohmmeter). When using method B to measure the motor efficiency, in order to maintain the accuracy and repeatability of the test results, it is required that the accuracy level of the instrument is not less than 0.2 (full scale).

Generally speaking, electronic instruments are versatile. Compared with passive instruments (non-electronic type), it has a very large input impedance, so there is no need to correct the reading due to the instrument's own losses. But high input impedance instruments are more sensitive to interference. Measures to reduce interference shall be taken based on practical experience.

The accuracy level of the instrument transformer used for measurement shall not be lower than level 0.2 (full scale).

4.2.3 Torque measuring instrument

The accuracy level of torque tester (including dynamometer and sensor) for general test should not be lower than level 0.5.

When method B (see 10.2.2) is used to determine efficiency, the accuracy level of the torque measuring instrument shall not be lower than level 0.2 (full scale).

the insulation resistance of each phase winding to the chassis and to each other shall be measured separately. If the three-phase winding has been connected inside the motor and only leads to three outlets, then measure the insulation resistance of all windings to the chassis.

After the measurement, the winding shall be discharged to ground.

5.2 Measurement of DC resistance of the winding in the initial (cold) state

5.2.1 Measurement of winding temperature in the initial state

Use a thermometer to measure the winding temperature. The motor shall be placed indoors for a period of time before the test. The difference between the winding temperature measured by a thermometer (or embedded thermometer) and the cooling medium temperature shall not exceed 2K. For large and medium-sized motors, the placement time of the thermometer shall not be less than 15min.

5.2.2 Measurement methods

5.2.2.1 The DC resistance of the winding is measured with a double-arm bridge or a single-arm bridge. When the resistance is 1Ω or less, it must be measured with a double-arm bridge or an instrument of equivalent accuracy and capable of eliminating the influence of the measuring wire and contact resistance.

5.2.2.2 When using an automatic detection device or a digital micro-ohmmeter to measure the resistance of the winding end, the test current through the tested winding shall not exceed 10% of its current during normal operation, and the power-on time shall not exceed 1min. If the resistance is less than 0.01Ω, the current through the tested winding shall not be too small.

5.2.2.3 During measurement, the rotor of the motor is stationary. The resistance of the stator winding end shall be measured on the outlet end of the motor.

Measure 3 times for each resistance. The difference between each reading and the average of 3 readings shall be within ±0.5% of the average. Take the arithmetic average as the actual value of the resistance.

During the inspection test, each resistance can be measured only once.

5.2.3 If each phase winding of the motor has a beginning-end terminal to lead out, the resistance of each phase winding shall be measured. If the three-phase winding has been connected inside the motor and only three outlets are led out, the resistance can be measured between every two outlets. According to the measured resistance, the resistance value (Ω) of each phase is calculated according to formula (2) to formula (7):

6 No-load test

6.1 Determination of no-load current and no-load loss

6.1.1 It is recommended that the no-load test be carried out after the load test (if carried out). The input power shall be stable before reading and recording test data. The difference between the two readings where the input power is 30min apart shall not be greater than 3% of the previous reading. For water-air cooling motors, the water flow shall be cut off immediately after the load test.

During the inspection test, the time of no-load operation can be shortened appropriately.

6.1.2 The voltage of the rated frequency is applied to the motor under test. The voltage variation range gradually decreases from 125% of the rated voltage, of which it shall include 100% rated voltage test points. As the voltage decreases, the current gradually decreases. When the current has an inflection point, the voltage shall continue to be reduced. Until the current value appears when the current rises to more than 100% of the rated voltage, take 10 to 12 voltage points (approximately evenly distributed). However, at the inflection point of the current, the measuring point shall be properly encrypted.

At each voltage point, measure I_0, U_0, P_0, and it shall measure θ_0 or R_0. According to the proportional relationship between temperature and resistance, use the initial resistance R_1 of the winding measured before the test, the initial temperature θ_1 and the measured temperature at each point, the terminal resistance R_0 at each voltage point can be determined.

When measuring motor efficiency according to method B (see 10.2.2), θ_0 or R_0 must be measured at each point;

The terminal resistance of the stator winding can also be determined by a) or b) of this article.

During the inspection test, only I_0 and P_0 can be measured when $U_0=U_N$.

a) The resistance value of the stator winding at each voltage point can be determined by linear interpolation. The starting point is the resistance value before the highest voltage point reading. The end point is the resistance value after the lowest voltage point reading.

b) After no-load test, immediately measure the resistance of the stator winding end. Use this resistance as the resistance value at each voltage point.

6.2 Determination of the sum of iron consumption P_{Fe} and wind abrasion

drives the motor under test as a generator running at no load at synchronous speed. Measure the outlet voltage U_{ab}, U_{bc}, U_{ca} of the tested motor separately. Take the average value as the no-load back EMF line voltage value. Record the temperature and ambient temperature of the stator core of the motor at this time.

6.3.2 Minimum current method

The motor runs stably under no-load operation at rated voltage and rated frequency. Adjust the external terminal voltage of the motor to minimize the no-load current. The applied terminal voltage at this time can be approximated as the no-load back EMF of the motor. Respectively measure the outlet voltage U_{ab}, U_{bc}, U_{ca} of the tested motor. Take the average value as the approximate value of the no-load back EMF line voltage value. Record the temperature and ambient temperature of the motor core at this time.

7 Stall test

7.1 Measurement of current, torque and power during stall

Stalling test is conducted when the motor is close to the actual cold state. Before the test, the rotor position corresponding to the maximum stalled-rotor current and the minimum stalled-rotor torque shall be determined with a low voltage in advance as much as possible. During the test, the rotor shall be blocked.

The rotor oscillates greatly when the motor is stalled. It shall consider measures to reduce fluctuations. During the test, it can first adjust the power supply voltage to less than 20% of the rated value. Connect to the motor under test. Maintain the rated frequency. Increase the power supply voltage as soon as possible. After electrical stabilization, quickly read stable readings of voltage, current, input power and torque simultaneously. To avoid overheating of the motor, the test must be carried out quickly.

7.1.1 Measure the characteristic curve of stalled rotor, that is, the relationship between the current I_K, torque T_K and the applied voltage U_K during stalling, as shown in Figure 2.

the reading is to first read the reading at the maximum load, then read the reading at the lower load.

8.2 Rated voltage load test

The test shall be conducted at rated voltage and rated frequency. Before starting to read the test data, the difference between the stator winding temperature and the temperature measured during the rated load thermal test shall not exceed 5°C.

Load the motor with suitable equipment (such as dynamometer, accompanying test motor). Use a torque measuring instrument that meets the requirements of 4.2.3 to measure the torque.

Load the motor at 6 load points. 4 load points are roughly evenly distributed between not less than 25% ~ 100% of rated load (including 100% of rated load). Choose 2 load points between 100% but not more than 150% of rated load. The process of loading the motor starts from the maximum load. Gradually reduce to the minimum load in sequence. The test shall be carried out as quickly as possible to reduce the temperature change of the motor during the test.

At each load point, measure U, I_1, P_1, T_d, f (or n), θ_t (or R_t) and θ_f.

It is recommended to use a temperature sensor (embedded at the end of the stator coil) to measure the temperature of the winding.

When measuring the motor efficiency according to method B, it must measure θ_t or R_t at each point.

The resistance value of the stator winding at each load point can also be determined by the method specified in a) or b) below.

a) The resistance value at each load point of 100% rated load and above is the resistance value before the maximum load point reading. The resistance value of each point of less than 100% rated load is determined according to the linear relationship with the load. The starting point is the resistance value at 100% rated load. The end point is the resistance value after the minimum load reading.

b) After the load test, immediately measure the resistance of the stator winding end. Use this resistance as the resistance value of each load point.

9 Determination of various losses

9.1 I^2R loss of stator winding at specified temperature [see formula (15)]

calculate efficiency.

10.2.1.1 Test process

During the test, the motor under test shall reach thermal stability under the rated load. Carry out the load test according to the method specified in 8.2.

10.2.1.2 Calculation format

Calculate the motor performance according to format A given in 16.1.

10.2.2 Method B: Loss analysis and indirect measurement of stray loss by input-output method

Measure electric power (including instrument transformer). The accuracy level of the instrument used for torque and speed shall meet the requirements of 4.2.2, 4.2.3, 4.2.4 and 4.2.5. This is particularly important for measuring the efficiency of the motor by using method B.

10.2.2.1 Test procedures

Method B test is mainly composed of three parts: rated load thermal test (see 11.7.1), load test (see 8.2) and no-load test (see 6.1). It is recommended to conduct thermal test first, which is conducive to the stability of motor friction loss. Immediately conduct the load test after. Conduct the no-load test at last. If the test cannot be carried out continuously in the above order, the motor must reach the thermal stability of the rated load thermal test before the load test.

10.2.2.1.1 Load test

The test shall be conducted in accordance with the requirements of 8.2 and relevant data shall be measured. Before starting to record the test data, the difference between the stator winding temperature and the maximum temperature recorded in the rated load thermal test shall not exceed 5°C. The test shall be carried out as quickly as possible to reduce the temperature change of the motor during the test.

According to the method proposed in Annex A, obtain the torque reading correction value k_d. The dynamometer or torque sensor shall be calibrated in the same direction as the load test.

10.2.2.1.2 No-load test

See 6.1 for the no-load test. Before starting to record the test data, the motor shall be run without load until the input power is stable (see 6.1).

10.2.2.2 Determination of various losses

Since the small error in measuring resistance shall cause a large error in determining the temperature, the instrument required in 4.2.5 shall be used to measure the winding resistance. If possible, the second instrument can be used for inspection. The initial resistance and the resistance at the end of the test shall be measured by using the same instrument.

11.3.3 Embedded thermometer method

This method measures the temperature with a thermocouple or resistance thermometer installed in the motor.

Specially designed meters shall be used with resistance thermometers, so as to prevent the introduction of significant errors or damage to the instrument due to the heating of the resistance thermometer during measurement. Many common resistive measurement devices may not be suitable because there may be a considerable current flowing through the resistance element during measurement.

11.4 Temperature reading

11.4.1 General instructions

The following clauses introduce 3 methods of temperature measurement, used to measure the temperature of the winding of the motor, the stator core, the cooling medium entering, and the cooling medium discharged after being heated. Each measurement method has its own characteristics, suitable for measuring the temperature of specific parts of the motor.

11.4.2 Thermometer method

During the thermal test, use the thermometer method (see 11.3.1) to measure the temperature of the following components. If required, it can be measured after shutdown.

a) Stator coil, at least in 2 places;

b) Stator core, for large and medium-sized motors, at least in 2 places;

c) Ambient temperature;

d) The air discharged from the base or exhaust vent or the internal cooling medium discharged from the motor with a circulating cooling system to the inlet of the cooler;

e) Machine base;

f) Bearing (if it belongs to motor parts).

11.6.1 Determination of winding temperature

The temperature of the motor winding is measured by the resistance method. If the motor has a buried thermometer, use a thermometer.

11.6.2 Determination of core temperature

The core temperature is measured with a temperature detector or thermometer. For large and medium-sized motors, the thermometer shall be no less than 2. Take the highest value as the core temperature.

11.6.3 Determination of bearing temperature

Bearing temperature is measured with a thermometer. For sliding bearings, the thermometer is placed in the temperature measuring hole of the bearing or near the surface of the bearing pad. For rolling bearings, the thermometer is placed closest to the outer ring of the bearing.

11.7 Thermal test method

The thermal test method shall use the direct load method.

11.7.1 Direct load method

The thermal test of the direct load method shall be performed at the rated frequency, rated voltage, rated power or nameplate current.

During the test, the tested motor shall maintain the rated load until the temperature rise of each part of the motor reaches the thermal stable state. During the test, record the voltage U, current I_1, input power P_1, frequency f, speed n, torque T_d, winding temperature θ_N and the temperature of stator core, bearing, air duct inlet and outlet cooling medium and surrounding cooling medium θ_a of the tested motor every 30min.

During the test, measures shall be taken to minimize changes in the temperature of the cooling medium.

If the temperature rise of the winding is determined by extrapolation, the resistance of the winding shall be measured immediately after the motor is turned off. And determine the resistance R_N after the rated load thermal test according to 11.7.5. For motors that use external coolers and ducted cooling, the supply of cooling medium shall be stopped while the motor is disconnected from the power supply.

If the temperature rise test is performed with the nameplate current, the winding temperature rise $\Delta\theta_N$(K) corresponding to the rated power is converted according to the following method [see formula (30) and formula (31)]:

12 Measurement of out-of-step torque

12.1 Overview

Out-of-step torque is measured by direct load method. During the test, a torque measuring instrument, brake, dynamometer or calibrated DC generator with uniformly adjustable load shall be used as the load. The motor under test shall be connected to a power supply that is actually balanced at the rated frequency and rated voltage. Adjust the tested motor to run under rated load. Then gradually increase the load of the tested motor to make it out of step. Torque value measured from torque measuring instrument, brake or dynamometer at the moment of out-of-step shall be the out-of-step torque of the tested motor.

a) Torque measuring instrument method;

b) Brake, dynamometer or corrected DC motor method.

When using the above test methods, the measurement shall be carried out at the rated frequency and rated voltage. If the test voltage cannot reach the rated voltage, the out-of-step torque value shall be converted according to 12.4.

12.2 Torque measuring instrument method

When measuring the out-of-step torque with the torque measuring instrument method, an automatic recorder can be used to directly describe the torque-speed characteristic curve and the relationship between the voltage of the tested motor terminal and the speed. The out-of-step torque is obtained from the curve.

During the test, the motor under test shall be prevented from overheating and affecting the accuracy of the measurement.

When the DC motor is used as the load, the motor under test is coupled with the sensor and the DC motor with a coupling. The DC motor is excited separately, and its armature is powered by an adjustable voltage and variable polarity power supply. The motor under test shall be connected to a power supply that is actually balanced at the rated frequency and rated voltage. The direction of the tested motor and the DC motor shall be consistent. Adjust the power supply voltage of the DC motor. Gradually increase the load of the tested motor to make it out of step. The torque value at the moment of out-of-step is the out-of-step torque T_{p0}.

12.3 Brake, dynamometer or corrected DC motor method

If the load of the tested motor is a brake or a dynamometer, the out-of-step torque can be read on the brake or dynamometer at the instant of out-of-step.

$$t_{piN} = \left(\frac{U_N - U'}{U - U'}\right)^2 \cdot \frac{P + P_{fws}}{(1-s)P_N} \qquad \cdots\cdots(36)$$

If the point where the slip rate is 0.05 in the test is not easy to establish accurately, then the load of the motor under test can be adjusted to make the slip rate around 0.05 and take 4~5 points. Calculate the torque as above. Then make a curve of torque to slip. Determine the torque value from the curve when the slip rate is 0.05.

Calculate the characteristic curve of torque and speed by torque measuring instrument. Obtain the nominal pull-in torque value from the point where s=0.05 on the curve.

13.1.2 Acceleration method

The tested motor is connected to the rated frequency. The voltage can be adjusted on the actual balanced power supply. Start the motor as a no-load motor. The power supply voltage shall be adjusted to enable the motor from 30%n_N to n_N in about 1.5 min. During acceleration, the power supply voltage and frequency remain unchanged. If the minimum voltage at which the motor can start from a standstill does not meet the above requirements, then the power supply voltage shall be further reduced until the above requirements are met. But at this time the motor shall use other methods to help start (for example, use crane to help start or start with higher voltage first, then cut off the power supply to slow down the motor. When the motor speed drops below 30% n_N, add the required voltage to test). In the range of 30%n_N~80%n_N speed, measure the speed every 5s~10s and record the time. It shall be recorded every 3s~5s within the range of 80%n_N~100%n_N. During the test, pay attention to whether the motor is overheated.

When using a fast recorder test, the time to accelerate to full value can be faster than the above regulations.

Make the curve of speed versus time from the test data, as shown in Figure 4. Find the slope d_n/d_t of the curve at 95%n_N. The slope can be determined by the following method. Take point a at 95%n_N on the curve as the center. Take two points b and c equidistant from a on the curve (the ordinate of point b shall not exceed n_N). The difference between the ordinate of these two points is Δn. The difference between the abscissa is Δt. The slope of the curve is Δn/Δt.

at this speed without increasing speed). Disconnect the power supply of the motor under test. Adjust the dynamometer or correct the power supply voltage of the DC motor so that its speed is about 1/3 of the intermediate speed. Then, close the power supply of the motor under test, quickly adjust the power supply voltage (or excitation current) of the dynamometer or correct the power supply voltage of the DC motor. Until the dynamometer's dynamometer reading or the armature current of the dc motor has a minimum value, read this value and the terminal voltage of the motor under test. When using a corrected DC motor, it is necessary to read the speed value at the same time.

When the dynamometer is used as the load, when the dynamometer and the motor under test have the same direction and the minimum torque cannot be measured, the polarity of the dynamometer power supply voltage can be changed, and the test can be performed.

During the test, the motor under test shall be prevented from overheating.

14.3 Torque measuring instrument method

When measuring the minimum torque with the torque measuring instrument method, the torque-speed characteristic curve of the motor under test must be measured. The minimum torque is obtained from the curve.

The torque speed characteristic curve can be manually drawn after point-by-point measurement, or directly drawn by automatic recorder. When measuring the torque and speed curve point by point, the measured points shall meet the requirements of correctly calculating various torques (locked torque, minimum torque, pull-in torque, out-of-step torque). Near these torques, the measurement points shall be as close as possible.

During the test, the motor under test shall be prevented from overheating and affecting the accuracy of the measurement. If necessary, the torque speed characteristic curve can be measured in sections.

When the DC motor is used as the load, the motor under test is connected to the sensor and the DC motor with a coupling. The DC motor is excited separately, and its armature is powered by an adjustable voltage and variable polarity power supply. The direction of the tested motor and the DC motor shall be consistent. Adjust the power supply voltage of the DC motor. Gradually increase the load of the motor under test. And read torque, speed and voltage at the same time. Or use an automatic recorder to describe the torque-speed characteristic curve and the relationship between the terminal voltage of the motor under test and the speed, see Figure 5.

Rotor oscillations are particularly severe when the permanent magnet synchronous motor is close to stall. Therefore, the load inertia of the connection

15.2 Determination of noise

The noise is measured according to GB/T 1006.9-1-2006.

15.3 Determination of vibration

The vibration is measured according to GB 10068-2008.

15.4 Short-term over-torque test

Short-term over-torque test shall be carried out at rated voltage and rated frequency.

During the test, the motor gradually increases the load in a hot state, so that its torque reaches the over torque value specified in GB 755-2008 or various types of motor standards. The duration is 15s.

If it is limited to equipment, it is allowed to use the stator current instead of the torque measurement during the test. At this time, the stator current value shall be equal to 1.1 times the over torque multiple times the rated current value.

15.5 Withstand voltage test

Test power frequency is power frequency. The voltage waveform shall be as sinusoidal as possible.

15.5.1 Test requirements

a) The withstand voltage test is conducted when the motor is stationary. Before the test, the insulation resistance of the winding shall be measured. If over-speed and short-time over-torque tests are required, this test shall be carried out after these tests. During the type test, the test shall also be performed after the thermal test is close to the thermal state of the motor.

b) During the test, the voltage should be applied between the winding and the chassis. At this time, other windings that are not involved in the test shall be connected to the core and the chassis. For motors with a rated voltage above 1kV, if both ends of each phase are led out separately, then each phase shall be tested one by one.

c) The test transformer shall have sufficient capacity, which can be selected according to the following methods:

1) For low-voltage motors, for every 1kV test voltage, the capacity of the test transformer shall not be less than 1kV;

2) For high-voltage motors, when the electric capacity is large, the capacity of the test transformer shall be greater than the calculated

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