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**Test procedures for converter-fed three phase cage induction
motors**

变频器供电三相笼型感应电动机试验方法

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Test procedures for converter-fed three phase cage induction motors

1 Scope

This standard specifies the test procedures for converter-fed three-phase cage induction motors.

This standard applies to converter-fed three-phase cage induction motors.

This standard does not apply to traction motors.

2 Normative references

The terms in the following documents become the terms of this standard by reference to this standard. For dated references, all subsequent amendments (not including errata content) or revisions do not apply to this standard. However, parties to agreements that are based on this standard are encouraged to study whether the latest versions of these documents can be used. For undated references, the latest edition applies to this Standard.

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

GB/T 755.2-2003, Methods for determining losses and efficiency of rotating electrical machinery from tests (excluding machines for traction vehicles) (IEC 60034-2:1972, IDT)

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)

IEC 60034-2-1:2007, Rotating electrical machines - Part 2-1: Standard methods for determining losses and efficiency from tests (excluding machines for traction vehicles)

$f_r = 10f_1$ – for six-step wave converter

$f_r = 6f_p$ – for PWM converter, the maximum is 100 kHz

Where:

f_1 – the maximum rated frequency;

f_p – the maximum pulse frequency (carrier frequency).

For six-step wave converters, ordinary electric instruments can meet these requirements; for PWM converters, wide-band equipment must be used, and electronic instruments with AD converters and digital data microprocessors are preferred.

Note 1: The two-meter method (Aron connection method) is not suitable for applications with high pulse frequency. This is because the sum of the input current phasors may not be zero due to the presence of capacitive current. Therefore, the measurement method of using one power meter per phase shall be adopted.

Note 2: The output harmonics of the converter and their main orders depend on the modulation method.

Note 3: For commonly used indicating instruments, the accuracy is specified for the nominal frequency (e.g., for 50 Hz ~ 60 Hz), and at the specified upper limit frequency, the accuracy level allows additional errors (e.g., 0.4% for 1 000 Hz). Electronic measuring instruments usually give a frequency range, which refers to the specified upper limit frequency. The specified accuracy applies to both 50 Hz or 60 Hz, as well as the specified upper limit frequency.

4.3 Measurement requirements

4.3.1 Voltage measurement

The signal wire of the measuring terminal voltage shall be connected to the motor terminal. If this connection is not allowed on site, the error caused by this shall be calculated and the reading shall be corrected. Take the arithmetic average of the three-phase voltage to calculate the motor performance.

The symmetry of the three-phase voltage shall meet the requirements of 4.2.1.2 in GB/T 1032-2005.

4.3.2 Current measurement

The line current of each phase of the motor shall be measured at the same time. Use the arithmetic average of the three-phase line current to calculate the performance of the motor.

When using a current transformer, the total impedance of the secondary loop instrument (including the connecting wire) as connected shall not exceed its rated impedance.

For motors with $I_N < 5$ A, current transformers shall not be used except for the locked-rotor test (see GB/T 1032-2005).

4.3.3 Power measurement

One three-phase power meter or three single-phase power meters shall be used to measure the input power. For occasions where the pulse frequency is not high, it may ignore the influence of the capacitance current. It may also use the two-meter (two single-phase power meters) method to measure the input power of the three-phase motor.

If the instrument loss affects the accuracy of the test results, the instrument loss and its error may be corrected according to Appendix A (see GB/T 1032-2005).

4.3.4 Torque measurement

The load test shall be carried out with a torque measuring instrument of appropriate specifications.

In addition to the locked-rotor test, the measurement of the maximum torque and the minimum torque, the nominal torque of the torque measuring instrument shall not exceed 2 times the rated torque of the motor under test. When the motor under test is at the rated speed, the measured wind friction loss of the coupling and dynamometer (or load motor) shall not be greater than 15% of the rated output of the motor under test, and the sensitivity of torque changes shall reach 0.25% of the rated torque. The mechanical power shall be measured accurately and the correction value k_d of the torque reading T_d shall be determined according to the method given in Appendix B (see GB/T 1032-2005).

4.3.5 Measurement of speed and slip

Measure the speed with a digital tachometer. If the induction coil method or flash tachometer is used to directly measure the slip, the power supply shall be the power supply of the motor under test (see GB/T 1032-2005).

4.3.5.1 Flash method

On the end face of the motor shaft, draw the same number of segments as the number of poles of the motor and illuminate them with fluorescent or neon lamps. The power frequency supplied to the flash fixture must be the same as the power frequency of the motor under test. During the test, use a stopwatch to measure the time t (s) required for the segment to rotate N times. Calculate the slip S_t according to formula (1):

$$S_t = \frac{60N}{t} \dots\dots\dots (1)$$

process is to first take the reading at the maximum load; then take the reading at the lower load.

8.1.2 Base rating load test

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

Use appropriate equipment (e.g., dynamometer, test motor) to load the motor. Use a torque measuring instrument that meets the requirements of 4.3.4 to measure the torque (only when using method A or method B).

Load the motor at 6 load points. The four load points are roughly evenly distributed between no less than 25% ~ 100% of the rated load (including 100% of the rated load), and two load points are appropriately selected between greater than 100% but no more than 150% of the rated load. The process of adding load to the motor is to start from the maximum load and gradually reduce it to the minimum load in sequence. The test shall be carried out as quickly as possible in order to reduce the temperature change of the motor during the test.

At each load point, measure U , I_1 , P_1 , T_d , n (or s_t), f , 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 fundamental loss of the motor according to method B, θ_t or R_t at each point must be measured; when determining the fundamental loss of the motor according to method E1, the method specified in a) below is allowed to be used to determine the resistance value at each load point; when determining the fundamental loss of the motor according to other methods specified in this standard, the method specified in b) below is allowed to be used to determine the resistance value at each load point.

- a) The resistance value at each load point at 100% rated load and above is the resistance value before the maximum load point reading. The resistance value at each point less than 100% rated load is determined in a linear relationship with the load. The starting point is the resistance value at 100% rated load, and the end point is the resistance value after the minimum load reading.
- b) After the load test, immediately measure the stator winding end resistance and use this resistance as the resistance value of each load point.

8.2 Determination of load characteristics of converter-fed motors

After the motor's thermal test, restart the motor and test the load characteristics. For example, the motor which has a reference frequency of 50 Hz, respectively adjust the

In motors powered by converters, voltage harmonics and current harmonics cause additional iron losses and winding I^2R losses in the motor stator and rotor. This additional loss is collectively called harmonic loss.

As far as motors powered by voltage source converters are concerned, many tests have proven that the size of harmonic losses has nothing to do with load changes (see IEC TS 60034-17:2006, Chapter 5).

The loss of the motor consists of two parts: fundamental loss and harmonic loss.

10.2.2.1 Harmonic losses

The harmonic loss P_{bh} is determined according to 6.2.2.

10.2.2.2 Fundamental losses

The motor under test is powered by a sine wave power supply, and the fundamental loss is determined according to the following methods specified in GB/T 1032-2005:

- a) Method B (see 10.4);
- b) Method E1 (see 10.5);
- c) Method F1 (see 10.6);
- d) Method G1 (see 10.7);
- e) Method H (see 10.8).

10.2.2.3 Determination of efficiency

The corrected sum of fundamental losses P_T is determined according to formula (34), the corrected total loss ΣP of the motor is determined according to formula (35), and the efficiency of the motor is determined according to formula (38).

10.3 Method A – input-output method (applicable to voltage and current source converters)

This method uses the ratio of measured output power to input power to calculate efficiency. Usually used for motors with an efficiency not greater than 90% (see 7.1 in GB/T 755.2-2003).

10.3.1 Test procedure

During the test, the motor under test is powered by the converter power supply and reaches a thermally stable state under rated load. Carry out load test according to the method specified in 8.1.2.

10.3.2 Calculation format

R_1 – the initial end resistance of the winding when the temperature is θ_1 , in ohms (Ω);

θ_a – the cooling medium temperature at the end of the thermal test, in degrees Celsius ($^{\circ}\text{C}$);

θ_1 – the winding temperature when measuring the initial end resistance R_1 , in degrees Celsius ($^{\circ}\text{C}$);

K_1 – constant. For copper windings, it is 235; for aluminum windings, it is 225, unless otherwise specified.

Since the deviation of the measured resistance will cause a large error when determining the temperature, the instrument required in 4.3.6 of GB/T 1032-2005 shall be used to measure the winding resistance. If possible, a second instrument can be used for inspection. The initial resistance and the resistance at the end of the test shall be measured using the same instrument.

11.1.3.3 Embedded thermometer method

This method uses a thermocouple installed in the motor or a resistance thermometer to measure the temperature.

Specially designed instruments shall be used with resistance thermometers to prevent the heating of the resistance thermometer from introducing significant errors or damaging the instrument during measurements. Many ordinary resistance-type measuring devices may not be suitable because considerable current may flow through the resistor element during the measurement.

11.1.4 Temperature reading

11.1.4.1 General description

The following subclauses introduce 3 temperature measurement methods for determining the temperature of the motor's windings, stator core, entered cooling medium, and discharged cooling medium after being heated. Each measurement method has its own characteristics and is suitable for measuring the temperature of specific parts of the motor.

11.1.4.2 Thermometer method

During the thermal test, the temperature of the following components can be measured using the thermometer method (see 11.1.3.1). If specified, measurements can be made after shutdown.

- a) stator coil, at least in 2 locations;
- b) stator core, for large and medium-sized motors, at least in 2 locations;

- c) ambient temperature;
- d) the air discharged from the machine base or exhaust ventilation duct or the internal cooling medium discharged from the motor with a circulating cooling system to the cooler inlet;
- e) machine base;
- f) bearings (if they are motor components).

The temperature sensitive element shall be placed where the highest temperature can be measured. For the temperature of air or other cooling media in the incoming and outgoing airflow, the sensitive element shall be placed where the average temperature can be measured.

11.1.4.3 Embedded thermometer method

During the motor thermal test with an embedded thermometer in the winding, the winding temperature shall be measured using the embedded thermometer method (see 11.1.3.3) and written in a report. Generally, it is not required to take readings after shutdown.

11.1.4.4 Resistance method

The temperature of the stator winding can be measured using the resistance method (see 11.1.3.2) after shutdown. The resistance between any two wire terminals shall be measured directly at the motor outlet terminal, and the initial value and initial temperature of this resistance have been measured.

11.1.5 Determination of cooling medium temperature during thermal test

11.1.5.1 Air-cooled motor

For motors cooled by ambient air, several thermometers can be used to measure the cooling air entering the motor. The thermometer shall be placed about 1 m ~ 2 m away from the motor, with the ball at half the height of the motor, and shall be protected from the influence of external radiant heat and airflow. Take the arithmetic mean of the thermometer readings as the cooling medium temperature.

11.1.5.2 External cooler motor

For motors using external coolers and ducted ventilation cooling, the temperature of the cooling medium shall be measured at the entrance of the cooling medium into the motor.

11.1.5.3 Inner cooler motor

For motors which are cooled by internal coolers, the temperature of the cooling medium shall be measured at the outlet of the cooler. For motors which are cooled by water-cooled coolers, the water temperature shall be measured at the inlet of the cooler.

11.1.5.4 Determination of the cooling medium temperature at the end of test

11.1.5.4.1 Constant rating and intermittent duty motors

For motors with a constant rating and intermittent duty system, the cooling medium temperature at the end of the test shall be the average of the thermometer readings as measured at the same time interval during the last 1/4 of the entire test process.

11.1.5.4.2 Short-term rated motors

For a short-time rated motor, the cooling medium's temperature at the end of the test is, if the rating is 30 min or below, the average of the thermometer's readings at the beginning and the end of the test. If the rating is 30 min ~ 90 min, take the reading of the thermometer at the 1/2 of the test time and the reading of the thermometer at the end.

11.1.6 Temperature measurement of motor windings and other parts

11.1.6.1 Measurement of winding temperature

The temperature of the motor windings is measured by the resistance method. Priority shall be given to the dual-bridge live temperature measurement method. If the motor has an embedded thermometer, use the thermometer to measure it.

11.1.6.2 Measurement of core temperature

The core temperature is measured using a thermoscope or thermometer. For large and medium-sized motors, there shall be no less than 2 thermometers, and the highest value is taken as the core temperature.

11.1.6.3 Measurement of bearing temperature

The bearing temperature is measured by a thermometer. For sliding bearings, the thermometer is placed in the temperature measurement hole of the bearing or placed close to the surface of the bearing bush. For rolling bearings, the thermometer is placed closest to the outer ring of the bearing.

11.2 Thermal test method

The thermal test method has direct load method and equivalent load method. It shall give priority to the direct load method.

The equivalent load method includes reduced voltage load method, reduced current load method, and stator overlap frequency method. The equivalent load method is limited to

I_1 – the primary current of induction motor;

U_2 – auxiliary voltage;

f_2 – auxiliary power frequency;

P_1 – input power.

Note 1: The auxiliary power supply's phase sequence shall be the same as the main power supply.

Note 2: U_2 shall be smaller than U_1 (usually 10% ~ 20% of U_1). U_2 is the voltage value to be applied to produce the rated current I_1 .

Figure 6 – Test circuit diagram of stator overlap frequency method

When using the stator overlap frequency method, the phase sequence of the main and auxiliary power supplies applied to the tested motor windings shall be the same. The motor under test can be started separately by the main and auxiliary power sources before wiring. If the directions of rotation are the same, it is the same phase sequence.

During the test, first use the main power supply to start the motor under test, to make it run at no-load at rated frequency and rated voltage. Subsequently, start the auxiliary power unit and adjust its speed to a speed value corresponding to a certain frequency f_2 . For a motor with a rated frequency of 50 Hz, f_2 shall be selected within the range of 38 Hz ~ 42 Hz. Then, put the auxiliary power generator into excitation and adjust the excitation current, so that the stator current of the motor under test reaches the full load current value. During the loading process, the main power supply voltage shall be adjusted at any time, to keep the terminal voltage of the motor under test at the rated value; meanwhile keep the frequency f_2 unchanged. The full load current value of the tested motor at rated voltage can be determined according to the method of 10.6 or 10.8. The test requirements are the same as 11.2.1.1.

When adjusting the load of the motor under test, if the instrument pointer swings large or the vibration of the motor under test and the test power supply equipment is large, the auxiliary power supply voltage shall be reduced first; then another value of frequency f_2 shall be selected by adjusting the speed of the auxiliary power supply unit for the test again.

11.2.3 Initial state

The test shall be carried out continuously within the specified time (for motors of non-constant rating) or until the temperature stabilizes. Unless otherwise specified, the short-term rated thermal test can only be started when the temperature difference between each part of the motor and the environment is within 5 K.

11.2.4 Allowed overload

same as those during calibration. During the test, the excitation current shall remain unchanged.

During the test, connect the motor under test with the dynamometer or the calibrated DC motor by a coupling, so that the rotation direction of the two is consistent. Gradually increase the load of the motor under test until the dynamometer's reading or the armature current of the corrected DC motor has the maximum value; read this value and the terminal voltage of the motor under test. When using a calibrated DC motor, read the speed value at the same time.

During the test, the motor under test shall be prevented from overheating and affecting the accuracy of the measurement. The terminal voltage of the motor under test shall be measured on its outlet terminal.

12.3 Torque measuring instrument method

When using the torque measuring instrument method to determine the maximum torque, it shall measure the torque-speed characteristic curve of the motor under test. The maximum torque is obtained from the curve.

The torque-speed characteristic curve can be drawn manually after point-by-point determination; or can be drawn directly by an automatic recorder. For fractional horsepower and small motors, both methods can be used. The former shall be used for medium-sized motors which use rolling bearings. When determining the torque-speed characteristic curve point by point, the number of points measured shall meet the needs of correctly obtaining various torques (maximum torque, minimum torque, synchronous torque, locked-rotor torque). Near these torques, the measuring points shall be as dense as possible.

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

When a DC motor is used as the load, the motor under test is connected to the sensor and DC motor by a coupling. The DC motor is separately excited; its armature is powered by an adjustable voltage and variable polarity power supply. The rotation 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; read the torque, speed and voltage values at the same time. Or use an automatic recorder to describe the torque-speed characteristic curve, the relationship curve between the voltage at the motor terminal and the speed under test. When using an automatic recorder to plot the curve, it is recommended to measure two torque-speed characteristic curves when the motor speed under test is rising and falling; take the average value. The drawing time of each curve shall not be less than 15 s.

12.4 Torque tachometer method

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