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Test procedures for three-phase induction motors

三相异步电动机试验方法

(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), NEQ)

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Test procedures for three-phase induction motors

1 Scope

This Standard specifies the test requirements and test methods for three-phase induction motors.

This Standard is applicable to three-phase induction motors.

2 Normative References

The articles contained in the following documents have become part of this Standard when they are quoted herein. For the dated documents so quoted, all the modifications (excluding corrections) or revisions made thereafter are not applicable to this Standard. For the undated documents so quoted, the latest editions are applicable to this Standard.

GB 755-2008 Rotating electrical machines - Rating and performance

GB 10068-2008 Mechanical vibration of certain machines with shaft heights 56 mm and higher-measurement evaluation and limits of vibration severity

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

GB/T 21211-2007 Rotating electrical machines - Equivalent loading and super-position techniques - Indirect testing to determine temperature rise

GB/T 22715-2008 Impulse voltage withstand levels of form-wound stator coils for rotating a.c. machines

GB/T 22719.1-2008 Interturn insulation of random-wound winding for AC low-voltage electrical machines - Part 1: Test methods

GB/T 22719.2-2008 Interturn insulation of random-wound winding for AC low-voltage electrical machines - Part 2: Test limits

JB/T 7836.1-2005 Electric heater for electrical machine - Part 1: General technique specifications

JB/T 10500.1-2005 Embedded thermometer resistance for electrical machines – Part 1: General specification, measuring methods and examine rule

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)

4.3.2 Electrical measurement

4.3.2.1 Effective value

Unless otherwise stated, all measurement value of voltage and current are effective value (rms).

4.3.2.2 Current measuring instruments

Generally, the accuracy of current meters shall be no less than grade 0.5 of their full ranges (megameter excluded). To ensure the accuracy and repeatability of the test results when measuring the motor efficiency using Method B/B1 (see 11.1.2), it is required that the accuracy of the measuring instruments be no lower than grade 0.2 of the full range.

Roughly, the electronic instruments are multi-purpose. Compared with passive instruments (non-electronic), electronic instruments have large input impedance. Therefore, there is no need to amend the readings that may be caused by the instrument loss. However, due to the fact that instruments with high input impedance are sensitive to interferences, anti-interference measures shall be taken for these instruments in light with the practical experience.

4.3.2.3 Instrument transformers (or transducer)

The accuracy of instrument transformers shall be no less than grade 0.2.

4.3.2.4 Voltage measurement

The signal wire used to measure the terminal voltage shall be connected with the motor terminal. If this is not allowed on the site, it is required to calculate the corresponding error and correct the readings. Arithmetic mean of the three phase voltages (U_{UV}, U_{VW}, U_{WU}) shall be used to obtain the motor performance.

4.3.2.5 Current measurement

Each of the three line-currents of electric motors shall be measured concurrently. Arithmetic mean of the three phase currents shall be used to obtain the motor performance.

When using current transformer, the total impedance of the instruments connected with secondary circuit (including connecting wires) shall be no larger than the rated values.

For electric motors with $I_N < 5$ A, current transformer shall not be used except for the locked rotor tests.

4.3.2.6 Power measurement

Two-meter method (2 single-phase power meters) shall be used to measure the input power of 3-phase motors. Alternatively, 1 3-phase power meter or 3 single-phase power meters could be used.

If the instrumental loss may affect the accuracy of test data, please correct the instrumental loss and the error thereof in accordance with Attachment A.

4.3.3 Resistance measurement

4.3.3.1 Resistance measuring meter

5.1.1.3 Measuring method

For terminals of each phase winding that are extended out of the enclosures, the insulation resistance between each phase winding and enclosure shall be measured separately. For terminals of each phase winding that are connected within the motors, the insulation resistance between all the windings and enclosures shall be measured. For motors with wound rotors, the insulation resistance of stator windings and rotor windings shall be measured.

When measuring, the data shall be read 1 min after applying the test voltage with winding temperature recorded.

In case that absorption ratio is measured to be R_{60}/R_{15}, insulation resistance for 15s and 60s shall be measured.

If the polarization index is measured to be R_{10}/R_1, insulation resistance in 1min and 10min shall be measured.

After measuring the insulation resistance, each circuit shall be discharged against the ground.

5.1.2 Measurement of other insulation resistance

5.1.2.1 Measurement of bearing insulation resistance

Measurement of bearing insulation resistance uses megameters not exceed 1000V.

5.1.2.2 Measurement of embedded thermometer resistance

Measurement of embedded thermometer resistance according to JB/T 10500.1-2005.

5.1.2.3 Measurement of electric heater resistance

Measurement of electric heater resistance according to JB/T 7836.1-2005.

5.2 Measurement of DC winding end-resistance under practical (cool) state

5.2.1 Measurement of winding temperature θ_1 under practical cool state

The winding temperature shall be measured with a thermal meter. The motor to be measured shall be placed indoors for a certain period prior to the test. The difference between the winding temperature (measured with a thermal meter or embedded temperature detector) and the temperature of cooling agent shall not exceed 2K. For large- and medium-scale motors, the keeping time of thermal meters shall be no less than 15 min.

For motors practicing a short working system (S2 working shift), the difference between the winding temperature and the temperature of cooling agent, at the beginning of testing, shall be within 5K.

5.2.2 Measurement of Winding DC End-resistance

DC resistance between winding terminals U and V, V and W, W and U is named as end-resistance, which can be separately marked as R_{UV}, R_{VW} and R_{WU}. Winding DC end-resistance can be measured by bridge method, micro-ohmmeter method, DC voltmeter-ammeter method, etc.

Prior to the thermal test, all temperature measuring devices shall be inspected to ensure that the temperature measuring error won't be increased due to influence of the stray magnetic field.

6.2.2 Temperature Measurement of Totally-enclosed Motor Rotor and Other Parts

Temperature of totally-enclosed motor rotor and other parts shall be rapidly measured with temperature measuring device after power off and machine halt.

6.3 Measurement of cooling agent temperature during thermal test

6.3.1 Air-cooling motors

For motors with an air-cooling system, the temperature can be measured with several thermometers distributed (2 to 3 point) in the ingoing cooling air. The thermometers shall be placed 1 to 2 meters away from the motor. The bulb shall be placed at 1/2 height of the motor. Avoid the impact of external radiation heat and flow on the temperature measurement. The arithmetic mean of thermometer readings shall be regarded as the cooling agent temperature.

6.3.2 Motors with external coolers

For motors with external coolers or cooling air channels, the cooling agent temperature shall be measured at the entrance of the agent to motors.

6.3.3 Motors with internal coolers

For motors with internal coolers, the cooling agent temperature shall be measured at the exit of coolers. For motors with water-cooling systems, the water temperature shall be measured at the entrance of coolers.

6.4 Measurement of cooling agent temperature on the completion of test

6.4.1 Continuous rating (S1) and interrupted duty motors (S3)

For motors with a continuous rating and interrupted duty system, the cooling agent temperature on the completion of the test shall be the average of several temperature readings measured at the same time interval within the last 1/4 time period of the whole testing process.

6.4.2 Short time rating motors

For motors with a short time rating less than 30 minutes, the cooling agent temperature on the completion of the test shall be the average of temperature readings recorded at the beginning and termination of the test. For motors with a short time rating between 30 to 90 minutes, the cooling agent temperature shall be the average of the temperature reading recorded at 1/2 test time and that recorded at the termination of the test.

6.5 Temperature measurement of motor windings and other parts

6.5.1 Temperature measurement of motor windings

The motor winding temperature shall be measured with a resistance thermometer and double-bridge electrified measurement is preferred. For motors with embedded temperature detectors, the detector shall be used for the measurement.

6.5.2 Temperature measurement of iron core

The iron core temperature shall be measured with a temperature detector or a thermometer. For large and medium motors, 2 meters at least shall be employed. Use the maximum of temperature readings as the iron core temperature.

6.5.3 Measurement of bearing temperature

The bearing temperature shall be measured with a temperature detector. For journal bearings, the thermometer shall be placed in the temperature hole or at the surface close to the bearing bushing. For rolling-contact bearings, the thermometer shall be placed close to the outer ring.

6.5.4 Temperature measurement of collector rings

On switching off the motor, temperature measurement of the collector rings shall be done immediately. The maximum of the temperature readings shall be regarded as the ring temperature.

6.6 Thermal test methods

6.6.1 General

Thermal test methods consist of direct method and indirect method, and the former method is generally preferred, indirect method for continuous rating motor only.

Indirect method includes reduced voltage load method, reduced current load method, and stator frequency method as well as other methods specified in GB/T 21211-2007.

6.6.2 Direct method

Motors tested with direct load method shall be measured at the rated frequency, rated voltage, and rated power or nominal current.

6.6.2.1 Continuous rating motors (S1)

When testing, the tested motor shall be operating under the rated load until the temperature rise of the motor remains thermal stability.

During the test, record the following data at a time interval of 30 minutes: voltage U, current I_1, input power P_1, frequency *f*, rotating speed *n* or speed drop s_t, torque T_t (for Methods A and B only), winding temperature θ_w, stator iron core temperature, bearing temperature, cooling agent temperature at the entrance and exit to air channel, and ambient cooling agent temperature θ_b, of the motor to be tested. If electrified measurement shall be used, the winding resistance shall also be measured at a time interval of 30 minutes and at the termination of the test.

6.6.2.2 Motors with a short time rating (S2 working system)

The test shall begin with the actual cool state and the time duration of test shall observe the rating specified. When testing, record the test data every 5 to 15 minutes, depending on the length of working time. For other test requirements, see 6.6.2.1.

6.6.2.3 Motors with an interrupted working rating (S3 working system)

When regulating the load exerted on the tested motor, it is advisable to reduce the voltage of the slave power supply first and then adjust the rotating speed of the slave supply in light of frequency f_2 before next testing, if the oscillation of meter pointer or the vibration of the tested motor and the power supply is appreciable.

The static variable frequency power supply that can meet the above test targets can be used for superimposed frequency test. Static variable frequency power supplies shall conform to the requirements of test power supplies (see 4.2).

6.6.3.4 Other thermal test methods

Other thermal test methods specified in GB/T 21211-2007, e.g. addition method of induction motor (see Clause 6 in GB/T 21211-2007) and equivalent load method of induction motor (see Clause 10 in GB/T 21211-2007).

6.6.4 Test procedure

6.6.4.1 Initial state

The test shall be done continuously within the specified time period (for interrupted rating motor), or until the temperature remains stable. Unless otherwise specified, the short time rating thermal test shall begin only when the difference between the motor temperature and the ambient temperature is smaller than 5 K.

6.6.4.2 Permissible overload

It will take a rather long time for motors with a continuous rating to reach a stable temperature. To shorten the time, it is allowable to have a proper overload (25% to 35%) when preheating the motor.

6.6.4.3 Temperature Measurement

During the test, alcohol thermometer can be used to measure the cooling medium temperature, stator core temperature, engine base temperature, bearing temperature, and cooling medium temperature of inlet and outlet.

During thermal test, local temperature detector can be used to measure temperature of each part of motor. When several local temperature detectors are adopted to measure the winding temperature, temperature reading on all temperature detectors shall be recorded, and the maximum value shall be taken as the winding temperature measured by local temperature detectors. No machine halt is required generally to read the temperature detector.

When the motor is equipped with several embedded temperature detectors, reading on all temperature detectors shall be recorded, and the maximum value shall be used as the winding temperature measured by embedded temperature detectors during thermal test.

Temperature of stator winding of the motor (wound motor rotor winding) shall be preferably determined by resistance measured after power off and machine halt (See 6.6.4.5 and 6.7.6.8).

6.6.4.4 Duration of Thermal Test

As for continuous-duty motor (S1), thermal test shall be conducted until the temperature rise between two continuous readings with interval of 30 min is within 1K. However, regarding motor

10.6.1 General description

Load stray loss means the sum of losses that are not included in the total loss, including stator loss I^2R, rotor loss I^2R, iron loss and air friction loss.

Test methods to determine the load stray loss: residual loss method, rotor takeout test and reversing test method, recommended value method and Eh-star method.

It shall give priority to the test method with relatively low uncertainty (See 11.1.2).

10.6.2 Residual Loss Method (Applicable to Method B)

The measured input power and output power difference in load test shall be regarded as apparent total loss. After deducting stator I^2R loss, rotor I^2R loss at test temperature, air friction loss, iron loss from apparent total loss, the remaining part is residual loss. Stray-load loss shall be obtained by linear regression analysis of residual loss test data and relevant analysis.

When method B is applied to determine efficiency, it is specified to use residual method to determine stray-load loss. The test program and calculation method for determining residual loss see 11.3.2.3.

10.6.3 Rotor Takeout Test and Reversing Test

10.6.3.1 Overview

This test comprises two independent tests.

a) Rotor takeout test — determine fundamental frequency stray loss

b) Reversing test — determine high frequency stray loss

10.6.3.2 Rotor Takeout Test — Determine Fundamental Frequency Stray Loss P_{sf}

10.6.3.2.1 Test Method

The rotor shall be taken out from motor, end cap of possibly induced current and other structural parts shall be in position. Stator winding is applied with symmetric low voltage of rated power. Test starts from large current value, and reduces gradually, reading of at least 6 points shall be measured within 1.1~0.5 times the rated current. The P_1, I_1, θ_1 (or R_1) of each point shall be read.

10.6.3.2.2 Measurement of fundamental frequency stray loss P_{sf}

The fundamental frequency stray loss P_{sf} can be obtained by subtracting static winding I^2R loss at the test temperature from the input power P_1:

$$P_{sf} = P_1 - 1.5I_1^2 R_t \qquad \text{..... (39)}$$

Where:

R_t — End-resistance of stator winding at test temperature, in ohm (Ω),

$$R_t — \ R_t = R_1 \times \frac{K_1 + \theta_t}{K_1 + \theta_1},$$

R_1 — stator winding initial (cold end) resistance, in ohm (Ω), determined according to 5.2.2.4;

θ_1 — winding temperature at measuring R1, in ohm (Ω), determined according to 5.2.1;

θ_t — the winding temperature measured during the test, in Celsius (°C), see 10.6.3.2.1;

I_1 — line current of stator, in Ampere (A), see 10.6.3.2.1;

P_1 — Input power, in Watt (W) see 10.6.3.2.1.

10.6.3.3 Reversal test — Measuring high frequency stray losses P'_{sh} for calculating

Dynamometer reversal method is preferred to be used.

10.6.3.3.1 Dynamometer reversal method

10.6.3.3.1.1 Test method

The dynamometer power at the same rotating speed as that of the motor to be tested shall be no larger than 15% of the rated power of the tested motor. When torque-measuring meter is used, the rated torque of the torque sensor shall be no larger than 15% of the rated torque of the tested motor.

Connect the dynamometer or the sensor (driven by other power machine) with the motor to be tested.

Motivate the rotor of the motor to be tested until it reaches the simultaneous speed in the reserve rotating field direction of the stator (if the power frequency used for the test is not the rated frequency, than the simultaneous speed shall correspond to the actual frequency). A 3-phase symmetric low voltage shall be applied to the stator winding of the motor to be tested, once the mechanical loss of the testing machine is stable. The test shall begin with the maximum current and decrease gradually. Measure 6 points within the range from 1.1 to 0.5 times of the rated current. For each point, the data P_1, I_1, T_d, and θ_t (or end-resistance R_t) shall be measured simultaneously.

It is expected that the motor will keep rotating at the simultaneous speed after the power supply for the tested motor is cut off. In this case, measure T_{d0}.

Rotor terminals shall be short circuited for motors with a wound winding.

NOTE: Reversal test power coefficient is low, power meter need be corresponding error corrections may be required.

10.6.3.3.1.2 Calculation method of high-frequency stray loss

$$P'_{sh} = P_d - P_{d0} - \left(P_1 - 1.5 I_1^2 R_t\right) \qquad \text{..... (40)}$$

Where:

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