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**Guide for the design and application of synchronous motors
for converter supply**

变频器供电同步电动机设计与应用指南

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Guide for the design and application of synchronous motors for converter supply

1 Scope

This document specifies the ratings, structural types, performance requirements, cooling methods, test methods and acceptance rules for three-phase or multi-phase electrically excited synchronous motors and permanent magnet synchronous motors powered by inverters, including requirements for inverters.

This document applies to synchronous motors driven by frequency converters.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

GB/T 755-2019, *Rotating electrical machines -- Rating and performance*

GB/T 997-2022, *Classification of types of construction, mounting arrangements and terminal box position (IM Code) for rotating electrical machines*

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

GB/T 1971-2021, *Rotating electrical machines -- Terminal markings and direction of rotation*

GB/T 1993-1993, *Cooling methods for rotating electrical machines*

GB/T 4942-2021, *Degrees of protection provided by the integral design of rotating electrical machines (IP code) -- Classification*

GB/T 10068-2020, *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 10069.3-2008, *Measurement of airborne noise emitted by rotating electrical machines and the noise limits -- Part 3: Noise limits*

- a) The inverter is generally configured according to the continuous load current capacity, short-time load current capacity and peak current capacity. In the selection process, the size of the specification, the peak and instantaneous value of the current, the RMS value of the motor current and the operating mode of the system should be properly controlled.
- b) When the motor and control system are used for loads where torque or frequency may change suddenly, the current size should be selected taking into account the maximum transient current peak value caused by the sudden change.
- c) When the motor's operating speed is required to change, if the power frequency changes more than the motor's speed, the effective current or peak current output by the control system may exceed the steady-state requirement.
- d) When the motor is running at low speed or overloaded, the motor loss increases and the efficiency decreases, so the power supply should ensure the operating requirements of the motor.
- e) The du/dt value of the inverter output is not greater than 3 kV/ μ s, and the common mode voltage is not greater than 1 kV. If there are special requirements, they can be negotiated separately.
- f) Frequency converters can be divided into two types: voltage source type and current source type. For AC-DC-AC frequency converters, if the intermediate DC link is connected in parallel with a filter capacitor, it is a voltage source type. If the intermediate DC link is connected in series with a filter inductor, it is a current source type. AC-AC frequency converters do not have an obvious DC intermediate link, but they also have voltage source type and current source type to meet the needs of the load. Usually, the internal resistance of AC-AC frequency converters is very small, and most of them are voltage source type.

4.2 Design of synchronous motor powered by inverter

When designing and selecting three-phase or multi-phase variable frequency synchronous motors, the following factors need to be considered.

- a) Unless otherwise specified, the motor shall be rated at continuous duty (S1). The rated value is the shaft power output by the motor at rated speed and rated voltage. The definition of the base rated value is to specify the voltage, speed, power or torque of the motor at point 3 in Figure 1 so that it meets the conditions at that point.
- b) The short-term overload capacity for occasional use refers to the ability of the motor to continuously withstand a load exceeding the rated load within a specified time when an accident rarely occurs or an emergency occurs. The short-term overload capacity for frequent use refers to the ability of the motor to repeatedly

requirements of the agreement.

- g) Because at a certain operating frequency of some types of inverters, the RMS value of the current input to the motor contains a considerable amount of harmonic current peaks and transient currents. Therefore, under full load, the total RMS value of the motor current is greater than the current corresponding to running under a sine wave power supply.
- h) The effect of cogging torque should be reduced when designing the motor.
- i) The corresponding harmonic content in the voltage or current of the inverter-powered motor is different from that when it is running on a sinusoidal power supply. It is important to analyze the torque reduction caused by harmonics and the impact of oscillating torque on the basic operating performance of the drive. Only by understanding the frequency spectrum of the inverter output current and/or voltage can the motor manufacturer calculate the details of the additional torque (especially oscillating torque) and losses generated during the operation of the motor and the impact of harmonics on the temperature rise of the windings. This is very different from the design of the effective part of the motor within the scope of GB/T 755-2019, so that each reduction factor is determined before the selection. When using intermittent, periodic, and variable load working systems, the time quota is a continuous quota based on the thermal effects encountered in actual use.
- j) Technical information communication should be considered when selecting inverters and motors, see Annex A.

4.3 Noise and vibration of synchronous motors powered by inverters

4.3.1 Factors affecting noise and vibration of inverter-powered synchronous motors

The motor and the driven equipment have natural resonant frequencies in radial, axial and different torsional modes. When frequency modulation control is applied to the motor, the system will be excited by the electromagnetic harmonics emitted by the inverter, which will affect the noise level, vibration level and torsional response of the transmission system. System design needs to consider these effects to ensure the normal operation of the transmission system.

When designing such motors, motor manufacturers should optimize the design to reduce noise and vibration, but factors other than the motor need to be considered comprehensively.

The noise and vibration of the motor are related to the following factors:

- a) electromagnetic design;

- b) inverter type;
- c) motor frame structure, resonance of rotating parts and oil film stiffness;
- d) mass size, equipment integrity and foundation structure;
- e) load and shaft connection method;
- f) air duct or external cooling device noise;
- g) vibration effect of ventilation device and main motor body.

4.3.2 Noise and vibration assessment of synchronous motors powered by inverters

The allowable vibration value of the motor shall comply with the following requirements:

- a) The speed should not exceed the maximum allowable value specified in GB/T 10068-2020 for speeds of 600 r/min and above;
- b) The double amplitude vibration value should not exceed 0.075 mm for speeds below 600 r/min.

Normally, the noise of a motor should not exceed the maximum allowable value specified in GB/T 10069.3-2008; or be agreed upon by the manufacturer and the user in the technical agreement.

4.4 Commutating reactor X_C limit

The commutating reactor X_C is closely related to the air-gap torque, stator current fluctuation, additional losses, vibration and noise. It determines the dynamic response of the motor.

For voltage source inverter X_C (p.u.) = 0.15~0.20

For current source inverter X_C (p.u.) = 0.08~0.10

For permanent magnet motor commutating reactor, it shall be agreed upon by the manufacturer and the user in the technical agreement.

4.5 Specialties of permanent magnet motor operation

The excitation of permanent magnet motor is uncontrollable (fixed magnetic flux), so the system designer should consider the impact of the induced voltage generated by the magnetic field of permanent magnet synchronous motor on the AC side during operation, such as:

- a) The short-circuit current generated by the short circuit of the internal winding when the motor rotates cannot be quickly cut off;
- b) The open-circuit voltage generated on the wiring terminals when the motor is idling;
- c) When the permanent magnet motor is running in weak magnetic field, the machine-end overvoltage condition is generated after the inverter fails and stops running.

5 Classification of inverter-powered synchronous motors

5.1 General industrial variable frequency synchronous motor

This type of motor is used to adjust the load by adjusting the mechanical speed of the motor to achieve energy saving. It is mainly used for loads such as fans and water pumps, and generally the S1 duty is the rated value basis.

5.2 Variable frequency synchronous motors for loads such as hoists

This type of motor has a continuous cycle S8 duty cycle with corresponding changes in load and speed.

5.3 Synchronous motors for metal rolling mills

5.3.1 Synchronous motors for metal finishing mills

This type of motor is generally unidirectional, but can be designed to run in both directions if necessary. The following special requirements should be considered for this type of rolling mill motor.

- a) There is enough margin for temperature rise under rated load: Under rated working condition and 100% rated load, the motor temperature rise is assessed according to 130 (B) grade insulation.
- b) Continuous overload capacity: Under rated working condition and 115% rated load, the motor can run continuously. At this time, the motor temperature rise is assessed according to 155 (F) grade insulation.
- c) There is a high short-term overload capacity: Except for special provisions, the motor overload requirements are shown in Table 1.
- d) Closed-loop speed control: A speed measuring device is used for closed-loop speed control.

mostly horizontal or vertical installation. Sliding bearings or rolling bearings are used for support.

6.2 The protection level is in accordance with GB/T 4942-2021, which is IP23, IP44 or IP54.

6.3 The cooling method is in accordance with GB/T 1993-1993, which is IC 86W or IC 37.

6.4 Sliding bearings are mostly lubricated with hydrostatic oil. Rolling bearings are lubricated with oil or grease. High-speed variable frequency motors also use magnetic bearings or air bearings.

7 Basic technical requirements for electric motors

7.1 If there is no special requirement, the thermal insulation grade of the motor is generally 155 (F) or 180 (H).

7.2 The motor rating is a continuous rating based on the S1 duty system.

7.3 The normal operating conditions of the motor are as follows.

- a) Altitude is not exceeding 1000 m. When the altitude of the operating location exceeds 1000 m or the cooling medium temperature decreases with increasing altitude, the temperature rise limit of the motor shall be revised in accordance with GB/T 755-2019.
- b) The ambient temperature is 0°C~40°C. The cooling air does not contain harmful gases such as acid, alkali and salt. The dust content in the air should not exceed 0.15 mg/m³.
- c) The reference voltages are: 600 V, 690 V, 1 200 V, 1 650 V, 3300 V, 6600 V, and 10000 V levels.

7.4 Motors without special requirements are generally tested at 1.2 times the maximum speed for 1 min.

7.5 Since the shaft voltage of the variable frequency motor is larger than that of the industrial frequency motor, in order to avoid the generation of shaft current, a shaft current grounding device is considered on the motor.

7.6 The terminal marking and rotation direction of the motor shall comply with GB/T 1971-2021.

8 Test methods for synchronous motors powered by inverters

8.1 The test shall be carried out in accordance with GB/T 1029 or GB/T 25442.

8.2 The vibration measurement shall be carried out in accordance with GB/T 10068-2020.

8.3 The noise measurement shall be carried out in accordance with GB/T 10069.1-2006.

8.4 The anti-demagnetization capability verification test of the permanent magnet motor shall be carried out in accordance with GB/T 25123.4-2015.

8.5 The characteristic test of the permanent magnet motor shall be carried out in accordance with GB/T 25123.4-2015.

8.6 The overspeed test of the permanent magnet motor shall be carried out in accordance with GB/T 25123.4-2015.

9 Accompanying documents, spare parts and warranty period

9.1 The following documents are provided with the variable frequency motor:

- a) Packing list;
- b) Product certificate;
- c) Operation and maintenance instructions;
- d) Technical conditions;
- e) Electrical switch data;
- f) Motor appearance drawing;
- g) Motor general assembly drawing.

9.2 Each motor can provide the following spare parts:

- a) One set of brushes (permanent magnet motors do not include brushes);
- b) One quarter set of brush box (permanent magnet motors do not include brush box);
- c) One set of bearings of each specification.

9.3 For variable frequency synchronous motors that are suitable for this document, the manufacturer shall guarantee that the motors can operate well within one year of use, or within two years from the date of shipment from the manufacturer, provided that the

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