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JAPANESE INDUSTRIAL STANDARD

Calculating Methods of Three-Phase Induction Motor Characteristics

JIS C 4207—1984

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Calculating Methods of Three-Phase
Induction Motor Characteristics

C 4207-1984

1. Scope

This Japanese Industrial Standard specifies, among calculating methods of three-phase induction motor characteristics, the methods shown below.

- (1) Calculating method of characteristics in accordance with circle diagram method
- (2) Calculating method of characteristics in accordance with loss separation method
- (3) Calculating method of the maximum starting current and the minimum starting torque.

Remark: The units and numerical values given in { } in this standard are in accordance with the International System of Units (SI), and are appended for reference.

Corresponding International Standards:

IEC 34-1 Rotating electrical machines, Part 1: Rating and performance

IEC 34-2 Rotating electrical machines, Part 2: Methods for determining losses and efficiency of rotating electrical machinery from tests (excluding machines for traction vehicles)

Reference Standards:

JIS C 4004-General Rules for Rotating Electrical Machines

JEC-37-1979 Induction Machines

2. Definitions

For the purposes of this standard, the following definitions apply:

- (1) maximum starting current The maximum effective value of line current flowing into the primary winding of an induction motor at standstill condition, under the rated voltage and rated frequency.

Remark: The current value shall be the value after extinction of transient phenomena.

- (2) maximum starting current of power source side when starting equipment is used The maximum effective value of line current flowing from power source into starting equipment, when the starting equipment connected to an induction motor at standstill condition is kept at starting position, under the rated voltage and rated frequency.

Remark: This current value shall be the value after extinction of transient phenomena.

- (3) minimum starting torque The minimum value of torque generated at shaft end of an induction motor at standstill condition, under the rated voltage and rated frequency.

Remark: This value shall be the value after extinction of transient phenomena.

- (4) minimum starting torque of induction motor when starting equipment is used The minimum value of torque generated at shaft end of an induction motor at standstill condition, when the starting equipment is kept at starting position, under the rated voltage and rated frequency.

Remark: This value shall be the value after extinction of transient phenomena.

3. Calculating Method of Characteristics in Accordance with Circle Diagram Method

Characteristics of a three-phase induction motor under operating shall, unless otherwise specified, be calculated in accordance with circle diagram method.

3.1 Classification of Circle Diagram Methods The circle diagram methods specified in this standard are classified as follows:

- (1) Type L circle diagram method
- (2) Special Type L circle diagram method

(3) Type T circle diagram method

(4) Special Type T circle diagram method

The circle diagram method means a method to obtain the characteristics, utilizing the fact that, when one phase of polyphase induction machine is expressed by equivalent circuit of Fig. 1 or Fig. 2, the locus of primary current vs. the variation of slip s will become a circle, on a complex plane.

In the said figures various characteristic values in one phase converted into star connection are shown, and the meaning of symbols is as follows:

V : Primary star phase voltage	r_1 : Primary resistance
I_1 : Primary current	r_2 : Secondary resistance (converted value to primary)
I_2 : Secondary current (converted value to primary)	x_1 : Primary leakage reactance
I_n : Exciting current at no-load	x_2 : Secondary leakage reactance (converted value to primary)
I_M : Exciting current	r_M : Iron loss resistance
s : Slip	x_M : Exciting reactance

Fig. 1. Type L Equivalent Circuit

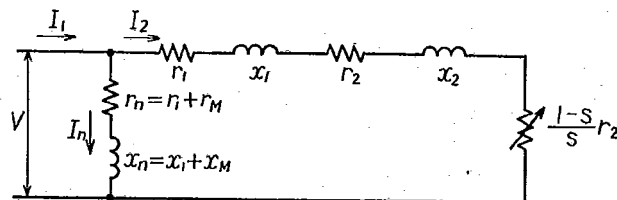
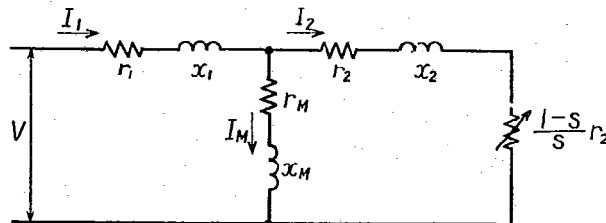


Fig. 2. Type T Equivalent Circuit



The circle diagram method based on the equivalent circuit of Fig. 1 is called Type L circle diagram method, the circle diagram method based on the equivalent circuit of Fig. 2 is called Type T circle diagram method.

In the case of special squirrel-cage induction machine or induction machine having special squirrel-cage effect, r_2 and x_2 in Fig. 1 and Fig. 2 will become functions of slip s , nevertheless, in the limited range of s , from no-load to nearly maximum torque, r_2 and x_2 may be regarded as constant and the characteristics can be calculated with sufficient accuracy for practical use. In this case, the circle diagram methods are called as special Type L circle diagram method and special Type T circle diagram method respectively.

In the case of calculating characteristics of special squirrel-cage induction machines such as double squirrel-cage or deep-slot squirrel-cage, of medium capacity two-pole wound-rotor induction machine, of high capacity wound-rotor induction machine, of induction machine having magnetic holding ring at end of secondary winding and solid rotor induction machine, the special circle diagram method shall be followed.

As Type T and special Type T circle diagram methods will give always some accurate result, as compared with Type L and special Type L circle diagram methods, however, the calculating procedure is complicated to some extent, and requires more work.

The basis to select Type L circle diagram method (or special Type L circle diagram method) or Type T circle diagram method (or special Type T circle diagram method) properly is not stated plainly, in this standard. However, in the case where no-load current is not less than 50 % of the rated current or not less than 20 % of the full voltage short-circuit current, it is preferable to employ Type T circle diagram method (or special Type T circle diagram method).

3.2 Calculation of Fundamental Quantity For the purpose of characteristics calculation by circle diagram method based upon the equivalent circuit of Fig. 1 or Fig. 2, the following fundamental quantity shall be obtained.

- (1) **Resistance of Primary Winding** Resistance of one phase of primary winding (converted value to star) at reference winding temperature shall be determined as follows:

$$r_1 = \frac{R_1}{2} \cdot \frac{235 + T}{235 + t} (\Omega)$$

where

R_1 : mean value of resistances of primary winding measured between terminals each other (Ω)

t : winding temperature at the time of resistance measurement ($^{\circ}\text{C}$)

T : reference winding temperature ($^{\circ}\text{C}$)

$T = 75^{\circ}\text{C}$ for classes A, E and B insulation

$T = 115^{\circ}\text{C}$ for classes F and H insulation

Remark: The insulation class to determine reference winding temperature means the insulation class corresponding to the assigned temperature rise for the machine and is not always the insulation class of actual winding. For example, even though class "F" insulation is made on the winding of a machine, if the machine is regarded as class "B" insulation concerning temperature rise extent, such insulation is also regarded as class "B" insulation for determination of reference winding temperature.

- (2) Active Component and Reactive Component of No-Load Current In the no-load test under the rated voltage of rated frequency, the rated voltage V_1 , no-load current I_0 , and input W_0 , shall be obtained, and then the active component and reactive component of no-load current I_0 , shall be obtained as follows:

$$\text{Active component of } I_0 \quad I_{0w} = \frac{W_0}{\sqrt{3} V_1}$$

$$\text{Reactive component of } I_0 \quad I_{0l} = \sqrt{I_0^2 - I_{0w}^2}$$

Remark: No-load current I_0 consists of exciting current (I_n in Fig. 1) at no-load and secondary current at no-load.

- (3) Active Component and Reactive Component of Locked Rotor Current at Reference Winding Temperature In the lock test carried out at the rated frequency, the applied voltage V_s' and input W_s' when the rated current or primary current I_s' close to it, is passed, are obtained and then the following fundamental values shall be obtained:

$$\text{Equivalent impedance of one phase} \quad Z_s' = \frac{V_s'}{\sqrt{3} I_s'}$$

$$\text{Resistance component of } Z_s' \quad R_s' = \frac{W_s'}{3 I_s'^2}$$

$$\text{Reactance component of } Z_s' \quad X_s' = \sqrt{Z_s'^2 - R_s'^2}$$

$$\text{Primary leakage reactance} \quad x_1 = \frac{X_s'}{2}$$

- (a) In the Case of Ordinary Squirrel Cage, Small Capacity Wound Rotor, and Medium Capacity Multi-Pole Wound Rotor Machines
The locked rotor impedance Z at reference winding temperature shall be obtained as follows:

$$R = R_s' \quad (\text{for classes A, E and B insulation})$$

$$= 1.13 R_s' \quad (\text{for classes F and H insulation})$$

$$X = X_s'$$

$$Z = \sqrt{R^2 + X^2}$$

The full voltage locked rotor current I_s corresponding to this impedance is:

$$I_s = \frac{V_1}{\sqrt{3} Z}$$

$$\text{Active component of } I_s \quad I_{sw} = I_s \frac{R}{Z}$$

$$\text{Reactive component of } I_s \quad I_{sl} = I_s \frac{X}{Z}$$

Remark: In the case of A, E and B insulations, as $Z = Z_s'$ following calculation may be performed.

$$I_s = I_s' \frac{V_1}{V_s'}, \quad W_s = W_s' \left(\frac{V_1}{V_s'} \right)^2$$

$$I_{sw} = \frac{W_s}{\sqrt{3} V_1} = W_s' \cdot \frac{V_1}{\sqrt{3} V_s'^2}$$

$$I_{sl} = \sqrt{I_s^2 - I_{sw}^2}$$

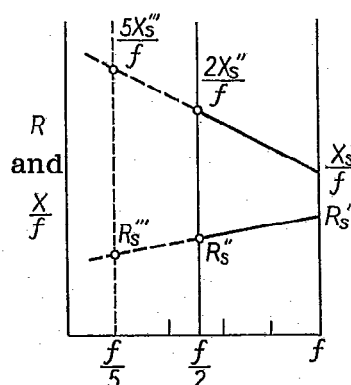
- (b) In the Case of Special Squirrel Cage, Medium Capacity Two-Pole Wound-Rotor, High Capacity Wound-Rotor Machine or the Like
For machines of these classes, in addition to the lock test at the rated frequency, also lock test is made at 1/2 of the rated frequency, the applied voltage V_s'' and input W_s'' when the rated current or primary current I_s'' close to it, is passed, are obtained and then the following calculation shall be made:

$$Z_s'' = \frac{V_s''}{\sqrt{3} I_s''}, \quad R_s'' = \frac{W_s''}{3 I_s''^2}$$

$$X_s'' = \sqrt{Z_s''^2 - R_s''^2}$$

R_s''' , X_s''' shall be obtained from R_s' , R_s'' , X_s' and X_s'' by drawing a figure as illustrated in Fig. 3 or from the following formulae:

Fig. 3



$$R_s''' = 1.6 R_s'' - 0.6 R_s'$$

$$X_s''' = 0.64 X_s'' - 0.12 X_s'$$

The locked rotor impedance Z at reference winding temperature shall be obtained as follows:

$$R = R_s''' \quad (\text{for classes A, E and B insulation})$$

$$= 1.13 R_s''' \quad (\text{for classes F and H insulation})$$

$$X = 5 X_s''' = 3.2 X_s'' - 0.6 X_s'$$

$$Z = \sqrt{R^2 + X^2}$$

The full voltage locked rotor current I_s corresponding to this impedance is:

$$I_s = \frac{V_1}{\sqrt{3} Z}$$

$$\text{Active component of } I_s \quad I_{sw} = I_s \frac{R}{Z}$$

$$\text{Reactive component of } I_s \quad I_{sl} = I_s \frac{X}{Z}$$

However, for the special squirrel cage motor with bar rotor;

$$h = \frac{2 X_s'' - X_s'}{R_s' - R_s''}$$

is calculated, and when $h > 1$, locked impedance Z at reference winding temperature is obtained by the following method, and it is preferable to determine above-mentioned I_{sw} and I_{sl} by using the Z so obtained.