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तीन फेजी प्रेरण मोटर के परीक्षण की मार्गदर्शिका

(पहला पुनरीक्षण)

Indian Standard

GUIDE FOR TESTING THREE PHASE INDUCTION MOTORS

(First Revision)

ICS 29.160.30

B U R E A U O F I N D I A N S T A N D A R D S
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Rotating Machinery Sectional Committee, ETD 15

FOREWORD

This Indian Standard (First Revision) was adopted by the Bureau of Indian Standards, after the draft finalized by the Rotating Machinery Sectional Committee had been approved by the Electrotechnical Division Council.

This standard was first published in 1967. This standard incorporates performance determination of induction machines by circle diagram method. Its scope was enhanced to include generators and special induction machines.

In this standard instructions for conducting and reporting the more generally applicable and acceptable tests to determine the performance characteristics of three phase induction motor are also covered. It is not intended to cover all possible tests nor those of research nature. The guidelines shall not be deemed as making it obligatory to carry out any or all tests discussed here in any given transaction.

For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated expressing the result of a test or analysis, shall be rounded off in accordance with IS 2 : 1960 'Rules for rounding off numerical values (*revised*)'. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

Indian Standard

GUIDE FOR TESTING THREE PHASE INDUCTION MOTORS

(First Revision)

1 SCOPE

This guide prescribes methods for conducting and reporting tests for three phase induction motor.

2 REFERENCES

The following standards are necessary adjuncts to this standard:

IS No.	*Title*
325 : 1996	Three-phase induction motors (*fifth revision*)
1248 (All parts)	Direct acting indicating analogue electrical measuring instruments and their accessories
4722 : 2001	Rotating electrical machines — Specification
4889 : 1968	Methods of determination of efficiency of rotating electrical machines
7816 : 1975	Guide for testing insulation resistance of rotating machines
12065 : 1987	Permissible limits of noise level for rotating electrical machines
13875 (All parts)	Digital measuring instruments for measurement and control

3 TERMINOLOGY

For the purpose of this guide, the definitions given in IS 325 shall apply.

4 ELECTRICAL MEASUREMENTS

4.1 Instrument Selection

The instruments used in electrical measurements shall conform to IS 1248 or IS 13875. Instruments with following accuracy shall be used:

a) For routine tests instruments of Class 2.5 accuracy shall be used.

b) For type tests instruments of the Class 0.5 accuracy shall be used.

4.2 Instrument Transformers

Where current and potential transformer are used corrections shall be made for ratio error in voltage and current measurement and for ratio and phase angle errors in power measurements.

4.3 Voltage

The voltage shall clearly approach sinusoidal wave-form and shall be balanced. Phase voltages shall be measured at the motor terminals. If at the time of conducting tests, voltage is nearly but not absolutely balanced, the arithmetical average of the phase voltages shall be used for calculating the machine performance.

4.4 Current

The line current in each phase of the motor shall be measured. It may not be equal in all the phases in which case the arithmetic average of the phase currents shall be used for calculating the machine performance.

4.5 Power

Power input to three phase machine may be measured by a single phase wattmeters connected as in two wattmeter method, alternatively, a single polyphase wattmeter may be used. The total watts read on a wattmeter shall be reduced by amount of I^2R losses in the voltage circuits of the instruments whenever this loss is a measurable portion of total watts read.

5 INSULATION RESISTANCE TEST

5.1 Insulation resistance shall be measured between winding and frame (earth).

5.1.1 Insulation resistance may be measured by an instrument like hand operated insulation resistance tester having a dc voltage of about 500 V.

5.1.2 For testing of insulation resistance for machines of output ratings 1 MW and above reference may be made to IS 7816.

6 HIGH VOLTAGE TEST

6.1 The high voltage test shall be applied between the windings and the frame, with the core connected to the frame and to the windings not under test and shall be applied only to a new and completed motor with all its parts in place under conditions equivalent to normal working conditions. The test shall be carried out at the manufacturers works soon after the completion of temperature rise test of the motor, where such a test is carried out.

6.1.1 It is generally advisable that the high voltage test should be conducted, if the insulation resistance is greater than the value derived from **30.2.2** of IS 4722.

6.2 In the case of motors with nominal voltage above 1 kV, when both ends of each phase are individually accessible, the test voltage shall be applied between each phase and the frame, with the core connected to the frame and to other phases and windings not under test.

6.3 The test voltage shall be of power frequency and shall be as near as possible to sine waveform. The test shall be commenced at the voltage of not more than one-half of the full test voltage. The voltage shall then be increased to the full value steadily or in steps of not more than 5 percent of the full value, the time allowed for the increase of the voltage from half to full value not being less than 10 s. The full test voltage shall then be maintained for 1 min in accordance with the values as indicated in Table 1. At the end of this period, the test voltage shall be rapidly diminished to one third of its full value before switching off.

6.4 During the routine testing of the motors of the rated output of up to and including 15 kW, the 1 min test may be replaced by a test note to be added: '5 kW increased to 15 kW comments are invited' 1 second 120 percent of the normal test voltage given in Table 1, the test voltage being applied by means of prods.

6.5 The test made on the winding on acceptance shall, as far as possible, not be repeated. If, however, a second test is made at special request of the purchaser, after further drying, if considered necessary, the test voltage shall be 80 percent of the voltage given in Table 1.

6.6 Completely rewound winding shall be tested at full voltage as for new motors. When user and a repair contractor have agreed to carry out high voltage tests in cases where windings have been partially rewound or in the case of an overhauled motor, the following provisions are recommended:

a) Partially rewound windings shall be tested at 75 percent of the test voltage for a new motor. Before the test, the old part of the winding shall be carefully cleaned and dried.
b) Overhauled motors, after cleaning and drying shall be subjected to a test at voltage equal to 1.5 times the rated voltage, with a minimum of 1 000 V, if the rated voltage is equal to or greater than 100 V, and a minimum of 500 V, if the rated voltage is less than 100 V.

7 RESISTANCE MEASUREMENT

7.1 General

The following two methods are commonly used for the measurement of resistance:

a) Drop of potential or voltmeter ammeter method, and
b) Bridge method.

Table 1 High Voltage Test
(*Clauses* 6.3, 6.4 *and* 6.5)

Sl No.	Motor or Part	Test Voltage rms
(1)	(2)	(3)
i)	Motors of size less than 10 000 kW	1 000 V+ twice the rated voltage with a minimum of 1 500 V
ii)	Motor of size 10 000 kW or more (*see* Note) Rated voltage *U*:	
	a) Up to 2 000 V	1 000 V + 2 *U*
	b) Above 2 000 V and up to and including 6 000 V	2.5 times *U*
	c) Above 6 000 V and up to and including 17 000 V	3 000 V + 2 *U*
	d) Above 17 000 V	Subject to special agreement
iii)	Secondary (usually rotor) winding of induction motors, if not permanently short circuited (for example, if intended for rheostatic starting):	
	a) For non-reversing motors or motors Reversible from standstill only	1 000 V + twice the open circuit standstill voltage as measured between slip rings or secondary terminals, with rated voltage applied to the primary windings
	b) For motors to be reversed or braked by reversing the primary supply while the motor is running	1 000 V + four times the open circuit standstill secondary voltage as defined in (iii) (a)

NOTE — High voltage tests on motors having graded insulation shall be the subject of special agreement.

7.1.1 Every possible precaution shall be taken to obtain the true temperature of the winding when measuring the cold resistance. The temperature of the surrounding air shall not be regarded as the temperature of the windings unless the motor has been standing idle under similar atmospheric temperature conditions for a considerable time.

7.1.2 If the resistance of winding is known at one temperature it may be calculated for any other temperature by using following formula:

$$R_2 = \frac{(235 + t_2)}{(235 + t_1)} \times R_1$$

where

R_2 = unknown resistance at temperature, t_2°C, and

R_1 = resistance measured at temperature, t_1°C.

NOTE — If R_1, R_2 and t_1 are known, t_2 may also be calculated from the above formula, 235 is not recognized for all materials; for instance, for aluminium the constant is 225.

7.2 Drop of Potential or Voltmeter Ammeter Method

In this method, a dc ammeter and d c voltmeter shall be used. Simultaneous readings of both voltage at motor terminals and current shall be taken when their values becomes steady. The relationship between *R*, *V* and *I* is as follows:

$$R = \frac{V}{I}$$

where

R = resistance, in Ω;

V = dc voltage, in V; and

I = dc current, in A.

7.2.1 Suitable ranges of instruments shall be chosen so that errors of observations are reduced to minimum. For the measurement of potential drop of less than 0.5 V the use of millivoltmeter is recommended.

7.2.2 The passage of high current may heat the windings appreciably and may cause erroneous measurement. It is therefore recommended that the current be applied as low as possible to obtain consistent reading and be limited to 10 percent of the rated current of the winding.

7.2.3 Care should be taken to compensate for the errors introduced in the measurements by the resistance of leads and contacts. Correction for the current drawn by the voltmeter shall be made, if it is appreciable.

7.3 Bridge Method

The resistance above 1 Ω may be determined with sufficient accuracy, if ordinary Wheatstone bridge is used. Resistance lower than 1 Ω shall be measured by Kelvin double bridge method also known as Kelvin-Thompson double bridge method.

7.3.1 *Wheatstone Bridge Method*

In using Wheatstone bridge method the resistance of the ratio arms shall be so selected that the values correspond as closely as possible to the resistance to be measured; the use of one ohm ratio coil should be avoided. The values of resistance thus measured include the resistance of connecting leads. Therefore, the resistance of leads should be subtracted from total measured resistance; otherwise it should be suitably compensated for.

7.3.2 *Kelvin-Thompson Double Bridge*

The double bridge compensates for resistance of leads or other connections. It also enables low resistance to be compared accurately with a standard one of the same order.

7.4 The rotor winding resistance shall be measured at the point of connection of the rotor windings to the slip rings so that slip ring resistance is eliminated from the measurement and true rotor winding resistance obtained. This will give more realistic rotor windings temperature.

7.5 The variation of resistance between phases to the extent of 5 percent may be permitted.

8 PERFORMANCE CHARACTERISTICS

8.1 No Load Test

8.1.1 This test is intended to find out the no load current, core loss and friction and windage losses.

8.1.1.1 The motor is run at no load at rated voltage and frequency until the watts input is constant. Reading of voltage, current and power input should be taken. This test shall preferably be conducted immediately after the temperature rise test.

8.1.2 The watts input is the sum of the friction and windage losses, core loss and no load primary I^2R loss. The sum of friction and windage losses and core loss is obtained by subtracting the primary I^2R loss at the temperature of the test from input watts.

8.1.3 The separation of friction and windage losses and core loss may be made, if desired, by obtaining readings of voltage, current and watts input at rated frequency and voltage from 125 percent of the rated voltage to the point where further voltage reduction will increase the current; this point is usually at 15 percent of the rated voltage. If instruments are changed during test, the readings taken with new instruments should overlap to ensure continuity. The primary loss I^2R shall be deducted from watts input and a curve of watts *versus* voltage is plotted and extended to zero voltage. The intercept with zero axis which represents friction and windage loss may preferably be found by plotting a second curve with the square of voltage as abscissa and watts as ordinate. At low saturations, the core loss varies nearly as square of voltage and therefore, the lower part of the curve may be shown as straight line. Typical curves are shown in Fig. 1.

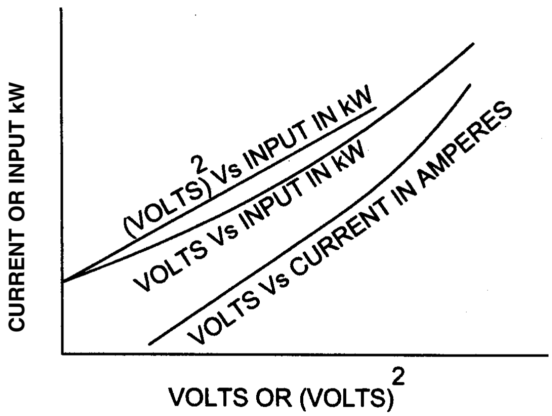


FIG. 1 DETERMINATION OF FRICTION AND WINDAGE LOSS

8.2 Open Circuit Test

8.2.1 *Open Circuit Voltage*

On wound-rotor motors, the voltage between all rotor terminals should be measured with rotor locked, if necessary and its winding on open circuit, with rated or reduced voltage and rated frequency applied to the stator. If any rotor unbalance is detected, it is recommended that the readings be taken with several rotor positions and an average obtained.

8.3 Locked Rotor Test (for Motors Having Output Rating Up to 37 kW)

This test is carried out to determine the soundness of rotor in case of squirrel cage induction motors and their starting current, power factor, starting torque and impedance. This also enables a circle diagram to be drawn in case of squirrel cage induction motors and wound rotor motors. This test may be carried out at reduced voltage, one of the readings may be at a voltage that will produce rated current of the motor. Locked rotor torque test is not done on wound rotor motors but on squirrel cage motors to determine the torque developed. Locked rotor current test is carried out on both squirrel cage and wound rotor motors.

8.3.1 It should be recognized that testing of induction motors under locked rotor conditions involves unusual stresses and high rates of heating. Therefore, it is necessary that,

a) the direction of rotation be established prior to the test;
b) the mechanical means of locking the rotor be of adequate strength to prevent possible injury to personnel or damage to equipment; and
c) as the windings gets heated very rapidly, the test shall be carried out as rapidly as possible. Care should be taken to ensure that the motor temperature does not exceed the value of permissible temperature of given class of insulation. The readings at any point shall be taken within 6s.

8.3.2 The following mechanical arrangements may be used to measure the developed torque:

a) Dynamometer,
b) Rope and pulley,
c) Brake or beam clamped rigidly to motor shaft, and
d) Torque transducer.

8.3.2.1 The torque should be measured with the rotor in various positions wherever possible and the minimum value shall be taken as starting torque.

8.3.2.2 The readings of voltage, current, frequency and power input should be taken. The starting torque and starting current should be extrapolated in accordance with **8.3.2.3** for rated voltage, when the test is carried out at reduced voltage.

8.3.2.3 For extrapolation of the test results at the rated voltage, the test shall be carried out at least at three test voltages. At each test voltage, the readings of voltage, current, torque, frequency and power input should be taken. Then a curve between values of the current and the applied test voltage should be drawn. Similarly another curve shall be drawn between the torque value and the square of the applied test voltage. The values of starting current and starting torque shall be extrapolated from these curves.

NOTE — Effect of the magnetic saturation is not considered in this test method.

8.4 Locked rotor test at rated frequency and reduced frequency (for motors above 37 kW or where direct measurement of torque is not possible).

This test is carried out when the performance parameters of a motor are to be determined by circle diagram or equivalent circuit diagram method. In this case, readings of voltage, current, frequency and power input are taken at frequencies and currents as specified below.

Normally the tests are carried out at rated current and frequency. For motors with deep bar effect/double cage rotor construction, tests are required at ½ of rated frequency. Tests are required at ¼ of rated frequency and at full load current and at twice the full load current when equivalent circuit method is used to calculate performance. The precautions listed under **8.3.1** are also applicable. Any suitable mechanical arrangement to prevent rotation of shaft during the test for example brake or beam clamped rigidly on motor shaft is adequate.

The locked rotor torque in such a case is calculated by the following formula from readings taken at rated frequency:

Locked rotor torque at test voltage ($T_{lr'}$):

$$= \frac{(1-s)\times(P_{si}-P_{cu})}{P_r} \text{ in percent full load torque}$$

where

P_{si} = input power to stator, in W;

P_{cu} = stator copper losses, at tested current and at reference temperature, in W;

P_r = rated output of motor, in W; and

s = full load slip.

And extrapolated locked rotor torque at rated voltage ($T_{lr'}$):

$$= \frac{(T_{lr'})\times(I_{st'})^2}{(I_{s'})^2} \text{ in percent full load torque}$$

where

$T_{lr'}$ = locked rotor torque in percent full load torque at tested voltage;

$I_{s'}$ = locked rotor current, at tested voltage, in A; and

$I_{st'}$ = locked rotor current, at rated voltage as determined by locked rotor test, in A.

NOTES

1 As this test is done at reduced voltage, core loss becomes negligible and ignored as compared to stator copper losses considered at the reference temperature instead of test temperature. This leads to calculated torque slightly lower than expected on actual torque measurement which is normally done at ambient temperature.

2 The same formula can be used even on motors below 37 kW, if direct measurement of torque is not done and results of locked rotor torque are required.

8.5 Pull Up and Pull Out Torque (for Motors Having Output Rating Up to 15 kW)

8.5.1 *Pull up Torque*

The motor shall be mounted with suitable loading arrangement and the rotor fully locked. The rated voltage at the rated frequency (*see* **13.2** of IS 325) shall then be applied to the motor terminals under locked rotor conditions. The loading on the motor shall then be reduced slowly when the rotor starts and picks up speed. The value of the torque at which the motor breaks away from the locked rotor condition and attains the speed corresponding to pull out torque condition shall be noted and reported as pull up torque.

NOTE — The test method for pull up torque for motors above 15 kW is under consideration.

8.5.2 *Pull out Torque*

The motor shall be mounted with a suitable loading arrangement and the rated voltage at the rated frequency (*see* **13.3** of IS 325) applied to the motor terminals at no load conditions. The load on the motor may then gradually be increased and the maximum load at which the motor stalls may be noted. The torque calculated at this point is the pull out torque.

NOTES

1 The motor should be disconnected from the supply immediately, if it stalls.

2 It may be noted that the motor should not be kept in the locked rotor condition for more than a few seconds since longer time lapse will endanger the windings.

3 The test method for pull out torque for motors above 15 kW is under consideration.

8.6 Determination of Starting Characteristics

8.6.1 *Locked Rotor Current of an Induction Machine*

The locked rotor current first of induction machines shall be determined from the result of the test specified in **8.3**, by either of the following methods. When the voltage for a constant current varies conspicuously depending on the rotor position at locked rotor test, the minimum value of the voltage shall be adopted.

8.6.1.1 *Direct proportion method*

Locked rotor test shall be carried out at a current equal to nearly 100 percent of rated current and the locked rotor current is determined from the result by the following formula:

$$I_{st} = I_{s1}\,(V_1/V_{s1})\,(A)$$

where

V_1 = rated voltage, in V;

V_{s1} = voltage at locked rotor test, in V; and

I_{s1} = current at locked rotor test (mean value of line currents), in A.

8.6.1.2 *Logarithmic proportion method (I)*

Locked rotor test shall be carried out at currents nearly equal to 100 percent and 200 percent of the rated current. The currents I_{s1} and I_{s3} at the locked rotor test and the voltages V_{s1} and V_{s3} corresponding to the currents shall be measured. Locked rotor current is determined by the following formula. This method applied to machines with totally-enclosed rotor slots.

$I_{st} = I_{st} (V_1/V_{s1})^B$

$B = 0.7a + 0.35$

$a = \log (I_{s3}/I_{s1})/\log (V_{s3}/V_{s1})$

8.6.1.3 *Logarithmic proportion method (II)*

Besides the locked rotor test in the logarithmic proportion Method (I), a locked rotor test shall be performed at a current nearly equal to 150 percent of the rated current. The current I_{s2} at the locked rotor test and the voltage V_{s2} corresponding to the current shall be measured. Locked rotor current is determined by following formula. This method applies to machines with totally-enclosed rotor slots.

$I_{st} = 1.04\ I_{s3} (V_{1/}V_{s3})$ 'y'

$y = 1.05_{y2} - 0.35(y_1 - 1)$ (when $y_2 > y_1$)

$= 0.7_{Y2} + 0.35$ (when $y_2 \leq y_1$)

$y_1 = \log (I_{s2}/I_{s1})/\log (V_{s2}/V_{s1})$

$y_2 = \log (I_{s3}/I_{s2})/\log(V_{s3}/V_{s2})$

8.7 Tests for Speed-Torque and Speed-Current Curves

8.7.1 Speed-torque characteristic is the relationship between torque and speed, embracing the range from zero to synchronous speed. This relationship when expressed as a curve, will include pull out torque, pull up torque and starting torque.

8.7.2 Speed-current characteristic is the relationship between current and speed.

8.7.3 *Method*

Speed-torque and speed-current tests may be carried out by the following methods:

a) Dynamometer;
b) Pony brake;
c) Rope and pulley; and
d) Calibrated machine.

8.7.3.1 Measurement of voltage, current and speed shall be made. The torque is obtained directly from dynamometer, pony brake, rope and pulley method and indirectly from calibrated machine method.

8.7.3.2 Speed-torque and speed-current tests shall be made at rated voltage or as near to it as practicable.

When it is necessary to establish values of current and torque at rated voltage, based on tests made at reduced voltage, it should be recognized that the current may be increased by a ratio somewhat greater than the first power of the voltage and torque by a ratio somewhat greater than the square of the voltage because of possible saturation of flux leakage paths. The relationship varies with design and, as a first approximation, is sometimes taken as current varying directly with voltage and torque with square of voltage. A more exact method of test is quite elaborate and calls for determining the rate of change of current and torque with voltage by establishing speed-torque and speed-current curves for at least two, preferably three or more, values of voltages.

8.7.4 It is necessary to avoid temperatures exceeding the limits of temperature-rise for a given class of insulation as specified in the relevant equipment specification.

8.7.5 For wound rotor motors, speed torque and speed-current tests may be taken between synchronous speed and the speed at which maximum torque occurs.

8.8 Load Test

8.8.1 Tests with load are carried out for determination of performance, such as efficiency, power factor, speed, temperature-rise and also to affirm general soundness of machines.

For all tests with load, the machine shall be securely fastened and in case of direct coupling, also properly aligned with the load. Load characteristics are obtained by taking readings at higher loads followed by those at lower loads. This is usually done at 125, 100, 75, 50 and 25 percent of the full load values.

When loading to rated conditions is not possible due to limitations in facility by either direct loading and indirect loading the super-imposition method of loading for temperature rise shall be considered in accordance with method given in Annex A.

8.8.2 *Methods of Loading*

One of the following six methods shall be selected by the manufacturer, depending on the available facilities:

Methods used by directly coupling a load to the motor on test as per **8.8.2.1**, **8.8.2.2**, **8.8.2.3** and **8.8.2.4** also provide data for the determination of efficiency, power factor, speed, etc, without the need for any further tests.

8.8.2.1 *Brake method*

Considerable care should be exercized in the construction and use of the brake and pulley. In this test, conditions should be such that the scale pointer remains practically stationery at any given load. Proper cooling, preferably water cooling, should be provided for the pulley.

8.8.2.2 *Dynamometer method*

The output of an induction motor may be calculated by the following formula:

$$\text{kW} = \frac{(T \times \text{rev/min})}{974}$$

where

T = rated torque, in kg.m.

8.8.2.3 *Calibrated machine*

If a dynamometer or brake and pulley is not available, the test motor may be loaded on a calibrated generator. The efficiency curve of such a generator shall be available.

8.8.2.4 *Uncalibrated machine*

If it is not possible to conduct any of the above three methods, the test motor may be loaded on an uncalibrated generator.

8.8.2.4.1 *Two frequency primary superimposed equivalent loading method*

In this method, load is generated on the motor through the combined action of primary supply at rated frequency and voltage applied to the stator winding and an auxiliary supply at different frequency and lower voltage superimposed simultaneously on the same primary winding (normally stator). Loading is adjusted by varying the amplitude of the two supply voltages. Further details of this method and the procedure to be followed are as specified in Annex B in particular.

Additional locked rotor tests are required for the determination of performance parameters other than temperature-rise when this method is employed.

8.8.2.4.2 *Two frequency secondary superimposed equivalent loading method (possible only for slip ring motors)*

In this method, load is generated on the motor by the simultaneous action of mains supply to the primary winding (stator) and an auxiliary supply at different frequency superimposed on the secondary winding (rotor).

Further details of this method and the procedure to be followed are as specified in Annex B and **B-3.2** in particular.

Additional locked rotor tests are required for the determination of performance parameters other than temperature-rise when this method is employed.

8.8.3 *Determination of Efficiency*

8.8.3.1 *Input-output method*

Input-output tests are carried out by the following three methods:

a) Dynamometer,
b) Brake and pulley, and
c) Calibrated machine.

8.8.3.2 *Segregated loss method*

Where an uncalibrated machine is used as load, this method is applied. The losses shall include those listed below:

a) *Fixed losses*:
   1) Core loss; and
   2) Friction and windage losses and brush friction loss, if any.
b) *Direct load loss*:
   1) I^2R loss in stator windings;
   2) I^2R loss in rotor winding; and
   3) Brush contact loss, if any.
c) *Stray load loss*:
   1) Stray load loss in iron, and
   2) Stray load loss in conductors.

Due allowance shall be made for stray losses in the verification of efficiency as specified in IS 4889. All I^2R losses shall be corrected to the reference temperatures appropriate for the class of temperature rise to **3.1** of IS 4889.

8.8.3.3 *Circle diagram methods*

The tests required to be performed to obtain readings required and the procedure for determination of performance shall be as specified in Annex C. Calculation of efficiency is done in accordance with **C-3.2** in particular.

8.8.3.4 *Equivalent circuit methods*

The test required to be performed to obtain readings required and the procedure for determination of performance shall be as specified in Annex C. Calculation of efficiency is done in accordance with **C-4.5.3** in particular.

8.8.4 *Slip Determination*

For the range of load for which the efficiency is determined, the measurement of slip is very important. Determination of slip by subtracting the value of speed obtained by means of conventional contact type tachometer from synchronous speed is not recommended. However, readings from digital non-contact type accurate tachometers with ± 0.1 percent accuracy can be used with frequency measured by an instrument of same accuracy class.

The slip can be measured by one of the following methods:

a) Stroboscope.
b) Slip-coil.
c) Magnetic needle.

   [Methods (b) and (c) are suitable for machines having a slip of not more than 5 percent].

   Alternatively, for indirect determination of slip.
d) Measurement of speed and frequency method.

8.8.4.1 *Stroboscope method*

On one end of the motor shaft, draw a single black radial line. The slip is readily measured by counting the apparent backward rotation of the black line over as given period of time.

8.8.4.2 *Slip coil method*

A suitable slip coil having approximately 700 turns of 1 mm diameter insulted wire is passed axially over the motor and its two ends are connected to centre zero galvanometer. When the motor is running the galvanometer pointer will oscillate. The number of oscillations shall be counted only in one direction, that is to the left or to the right for a period of say 20s. The following formula will give percentage slip:

$$S = \frac{n \times 100}{T \times f}$$

where

S = percentage slip;

N = number of oscillations;

T = time required for 'n' oscillations, in second; and

f = supply frequency.

8.8.4.3 *Magnetic needle method*

In this a magnetic needle is suspended on a sharp point so that it can rotate freely on the body of the motor in horizontal plane. The needle will oscillate and the number of oscillations will be counted for a period of say 20 s. The percentage slip may be found by using the formula given under **8.8.4.2**.

8.8.4.4 M*easurement of speed and frequency method*

This method is permissible only when the readings are taken using non-contact type accurate tachometers (generally digital) with ± 0.1 percent accuracy when the frequency is measured by an instrument of same accuracy class. The following formula will give percentage slip:

$$S = \frac{100(1 - N \times P)}{120 \times f} \text{ Percent}$$

where

f = supply frequency, in Hz ;

N = measured speed, in rev/min (rpm); and

P = number of poles.

8.8.4.5 *For equivalent loading methods*

The readings required to be taken and the procedure for calculations shall be as specified in Annex C.

8.8.5 *Power Factor Determination*

Power factor may be determined by one of the following methods:

a) *From readings taken on direct loading*:
   1) Watt to volt-ampere ratio;
   2) Two wattmeter readings; and
   3) Power factor meter.
b) *For equivalent loading method*:
   The readings required to be taken and the procedure for calculations shall be as specified in Annex C.

8.8.5.1 *Watt to volt ampere ratio method*

Power factor is obtained by ratio algebraic sum of wattmeter readings to volt-ampere readings.

For three phase,

$$\text{Power factor} = \frac{\text{Watts}}{3 \times \text{ Volts} \times \text{Amperes}}$$

8.8.5.2 *Two wattmeter readings method*

On three phase motor where load is pulsating the power factor so obtained may be checked by the following formula obtained from independent wattmeter readings.

$$\text{Power factor} = \frac{1}{\left|1 + 3\frac{W_1 - W_2}{W_1 + W_2}\right|^2}$$

where

W_1 = higher of two readings, and

W_2 = lower of two readings.

If W_2 gives a negative reading, it should be considered minus quantity. From the above formula, curves can be plotted of power factor *versus* ratio of lower wattmeter reading to higher wattmeter reading $(W_2)/(W_1)$. It is possible to obtain the power factor directly from these curves. If W_2 is negative the ratio $(W_2)/(W_1)$ should be considered a minus quantity.

$$\cos\theta = \frac{1}{2}\frac{(1+X)^3}{1+Y^3}$$

where

X = ratio of wattmeter readings like polarity, and

Y = ratio of wattmeter readings unlike polarity.

8.8.5.3 *Power factor meter method*

In this method, power factor meter is directly connected in the circuit and direct reading is obtained.

8.8.5.4 If two values of power factor determined by **8.8.5.1** and **8.8.5.2** do not agree for a three phase motor the test may be repeated to eliminate the error. However, in the case where the load is fluctuating power factor determined by **8.8.5.2** will be higher than that determined by **8.8.5.1**. In this case higher value shall be taken as correct reading. The difference is because of the inclusion of pulsating components of current in volt-ampere, which is a function of load rather than of motor itself. The power factor determined from the ratio of wattmeter reading is not affected by the presence of pulsating current.

8.8.5.5 *For equivalent loading method*

The readings required to be taken and the procedure for calculations shall be as specified in Annex C.

8.9 Temperature-Rise Test

8.9.1 This test is intended primarily to determine the temperature-rise on different parts of the motor while running at rated conditions. It can be done either by direct loading method or equivalent loading method. When loading to rated conditions is not possible due to limitations in facility, the superimposition method of loading for temperature-rise shall be considered in accordance with method given in Annex A. The value of temperature rise on test at reduced load and voltage (T_2) used in the formula to determine the full load temperature-rise can be by either by direct loading or by equivalent loading methods.

8.9.2 While preparing for temperature-rise test, the motor should be shielded from currents of air coming from adjacent pulleys, belts and other machines as incorrect results may be obtained, if this is not done. A small current of air may cause great discrepancy in results obtained. Sufficient floor space should be left between machines to allow free circulation of air. Under ordinary conditions, a distance of two meters is sufficient.

8.9.3 The duration of temperature-rise test is dependent on the type of rating of motor.

8.9.3.1 For motors with continuous rating the temperature-rise test should be continued till thermal equilibrium has been reached. Whenever possible, the temperature should be measured both while running and after shutdown.

8.9.3.2 For motors with short time rating, the duration of the test should correspond to the declared short time rating. At the end of the test the specified temperature-rise limits should not be exceeded. At the beginning of the test the temperature of the motor should be within 5ºC of that of the cooling air.

8.9.3.3 In the case of motors for periodic duty and for continuous duty with intermittent load, the test should be continued till thermal equilibrium has been reached. Unless otherwise agreed, the duration of one cycle should be 10 min, for the purpose of this test. Temperature measurements should be made at the end of no load periods for the purpose of establishing thermal equilibrium. At the end of first half of the last period of no load operation the temperature-rise shall not exceed the specified limit.

8.9.4 When thermal equilibrium is reached the motor shall be stopped as quickly as possible and measurements taken both while the motor is running and after shut down (wherever possible). No corrections for observed temperatures are necessary, if the stopping period does not exceed the values given below:

Rating kW	*Stopping Period* s
0-50	30
51-200	90

8.9.4.1 In case where successive measurements show increase in temperature after shut down, the highest value shall be taken.

8.9.4.2 Whenever rotor temperature also is required this is found out by recording the highest temperature. reached in the thermometers placed on he rotor bars and core in the case squirrel cage motors and on collector rings in the case of wound rotor motor. Thermometers should be read as soon as rotating parts come to rest.

8.9.5 In cases where the temperature can be measured only after the motor has come to rest (as in case of measurement of temperature-rise by resistance method) the cooling curve is plotted by determining the first points as rapidly as possible. In cases where the first measurement of temperature is made after the periods given in **8.9.4** from the instant of switching off the power, extrapolation of the cooling curve is carried out to determine the temperature at the instant of shut down. This may be achieved by plotting a curve with temperature reading as ordinates and time as abscissa and extrapolating back to the instant of shut down.

8.9.6 *Methods of Measuring Temperature-Rise*

The temperature-rise of a part of a motor shall be the difference in temperature between that part of the motor, measured by the appropriate method in accordance with **8.9.6.1** or **8.9.6.2** or **8.9.6.3** and the cooling medium measured in accordance with **8.9.7**. Three methods of determining the temperature of windings and other parts are recognized.

8.9.6.1 *Embedded temperature detector method*

Embedded temperature detectors are resistance thermometers or thermo-couples build in the machine during manufacture at points which are inaccessible when the machine is completed. This method is generally employed for the slot portion of stator windings.

At least six detectors shall be built in the machine, suitably distributed around the circumference and placed in positions along the length of the core at which the highest temperatures are likely to occur. Each detector shall be installed in intimate contact with the surface whose temperature is being measured and in such a manner that the detector is effectively protected from contact with cooling air. The location of the detectors shall be as follows:

Two coil-sides per slot — When the winding has two coil-sides per slot, each detector shall be located between the insulated coil-sides with in the slot.

More than two coil sides per slot each detector shall be located in a position between insulated coil sides at which the highest temperature is likely to occur.

NOTES

1 The embedded temperature detector method is not recognized for stator windings having only one coil-side per slot for which the resistance method shall be used with the same limits of temperature-rise. For checking the temperature of such a winding in service, an embedded detector at the bottom of the slot is of little value because it gives mainly the temperature of the iron core. A detector places between the coil and the wedge will follow much more closely the temperature of the winding and is, therefore, better for check tests, although the temperature there, may be rather low. The relation between the temperature measured at that place and the temperature measured by resistance should be determined by a heat test and a suitable limit for the temperature measured by embedded detector corresponding to the allowed temperature by resistance should be agreed upon.

2 In case where embedded temperature detectors may be undesirable they may be omitted by agreement and the resistance method used with the same limit of temperature-rise.

8.9.6.2 *Resistance method*

This method is generally applicable to the stator windings not employing embedded temperature detectors. It is the preferred method. In this method the temperature of the windings is determined by the increase in resistance of the windings.

When the temperature of a winding is to be determined by resistance, the temperature of the winding before the test measured by thermometer shall be practically that of the cooling air or gas.

The temperature rise $t_2 - t_a$ may be obtained from the ratio of the resistance by the formula:

$$\frac{t_a + 235}{t_1 + 235} = \frac{R_2}{R_1}$$

where

t_a = temperature of cooling air or gas at end of the test, ºC;

t_2 = temperature of the winding at the end of the test, ºC;

R_2 = resistance of the winding at the end of the test;

t_1 = temperature of the winding (cold) at the moment of the initial resistance measurement, ºC; and

R_1 = initial resistance of the winding (cold).

For practical purposes, the following alternative formula may be found convenient:

$$t_2 - t_a = \frac{R_2 - R_1}{R_1}(235 + t_1) + t_1 - t_a$$

8.9.6.3 *Thermometer method*

This method is applicable in cases where neither the embedded temperature detector method nor the resistance method is applicable.

The use of the thermometer method is also recognized in the following cases:

a) When it is not practicable to determine the temperature-rise by the resistance method, as in the case of low-resistance windings, especially when the resistance of joints and connections forms a considerable portion of the total resistance;
b) Singly layer winding, revolving or stationary; and
c) When, for reasons of manufacture in quantity, thermometer method alone is used, although the resistance method would be possible.

In this method, temperature is determined by thermometers applied to the accessible surface of the motor.

The term thermometer includes mercury or alcohol bulb thermometers as well as non embedded thermocouples and resistance thermometers provided the latter are applied to the points accessible to the usual bulb thermometer.

When bulb thermometers are employed in places where there is any varying or moving magnetic field, alcohol thermometers should be used in preference to mercury thermometers as the latter are unreliable under these conditions.

8.9.7 *Measurement of Cooling Air or Gas Temperature During Tests*

The cooling air temperature shall be measured by means of several thermometers placed at different points around and half way up the motor at a distance of 1 to 2 m, and protected from heat radiation and draughts. The value to be adopted for the temperature of the cooling air or gas during a test shall be the mean of the readings of the thermometers (placed as mentioned above), taken at equal intervals of time during the last quarter of the duration of the test.

8.9.7.1 In order to avoid errors due to time lag between the temperature of large motors and variations in the cooling air or gas, all reasonable precautions shall be taken to reduce these variations and errors arising there from.

8.9.7.2 In the case of cooling by means of forced ventilation, or where machines have water cooled air or gas coolers, the temperature of the air or gas measured, where it enters the motor, shall be considered as the cooling air or gas temperature.

8.9.8 *Temperature Correction*

8.9.8.1 *Motors specified for operation at altitudes in excess of 1 000 m*

For motors, specified for operation at an altitude higher than 1 000 m but not in excess of 4 000 m, no correction shall be made, if the difference between altitude during test and the specified altitude in service does not exceed 1 000 m. If, however, the specified altitude exceeds the test altitude by more than 1 000 m, the specified temperature-rise shall be reduced at the rate of one percent for each increment of 100 m by which the site altitude exceeds 1 000 m.

8.9.8.2 *Cooling air temperature for temperature-rise test*

A motor may be tested at any convenient value of cooling medium temperature less than 40°C, but whatever is the value of this cooling medium temperature, the permissible rise of temperature shall not exceed, during the test, those specified in the relevant equipment specification.

In the case of motors intended to operate under conditions in which the maximum cooling air temperature exceeds 40°C, the temperature-rise as given in the relevant specification shall be reduced as follows:

a) By 5°C, if the temperature of the cooling air exceeds 40°C by 5°C or less;
b) By 10°C, if the temperature of the cooling air exceeds 40°C by more than 5°C but not more than 10°C; and
c) By agreement, if the temperature of the cooling air is more than 10°C above 40°C.

Tests of temperature-rise may be carried out at any convenient cooling air temperature. When the temperature of the cooling air during test is lower than the stated site cooling air temperature by not more 30°C, no correction shall be made on account of such difference. When the temperature of the cooling air during test is lower than the stated site cooling air temperature by more than 30°C, the permissible temperature-rise on test shall be the permissible temperature-rise under specified site conditions reduced by a percentage numerically equal to one third of the difference between the specified temperature of the cooling air on site and the temperature of the cooling air on test where both temperatures are expressed, in ºC.

Example:

If the specified temperature of the cooling air on site is 56°C and the temperature of the cooling air on test is 20°C, the reduction in temperature-rise to take account of the difference is:

$$\frac{56-20}{3}=12$$

The permissible temperature-rise on test is, therefore,

$\frac{100-12}{100}$ = 88 percent of the temperature-rise on site.

These reductions apply to all the classes of insulation covered in this standard, the test being carried out at the manufacturer's works.

9 MEASUREMENT OF SHAFT CURRENTS AND VOLTAGES

9.1 Shaft currents and voltages may be produced in a machine due to various factors like dissymetries in the magnetic circuit, non inform flux distribution, eccentric air gap and electrostatic effects.

9.2 A test suitable for all 2 poles and higher capacity motors is given below.

9.2.1 The machine is run at no-load and at rated supply voltage and frequency. A rectifier type moving coil voltmeter of full scale deflection of 5 V (preferably of 1 V only) should be connected across the ends of the machine by means of solid copper prods firmly held in the shaft centres. When this is not feasible any smooth cylindrical surface outside the bearing may be used.

Alternatively, this measurement may be done by inserting a voltmeter between the shaft and the pedestal (in case of sleeve bearing).

9.2.2 The connecting leads used in this test should be of very low resistance.

10 MEASUREMENT OF NOISE

See IS 12065.

11 TEST OF MOTORS FOR OPERATION WITH FREQUENCY CONVERTERS

All tests with frequency converter may be specified together with the customer and the motor manufacturer in each case. When the motor is tested together with customer's frequency converter it is customer's responsibility to take care of the implementation of the frequency converter and necessary accessories.

Motors for operation with frequency converter are tested with sinusoidal supply as mentioned in this standard. Additional tests with frequency converter are as follows:

a) Temperature-rise test at rated load and speed;
b) Efficiency measurement by loss segregation method; and
c) Vibration level test at the highest speed.

Suitable power analyzer shall be used for measurement of voltage, current and input power.

ANNEX A

(*Clauses* 8.8.1 *and* 8.9.1)

SUPERIMPOSITION METHOD OF LOADING FOR TEMPERATURE-RISE

A-1 INTRODUCTION

A-1.1 The temperature-rise of an induction motor under rated conditions is conventionally evaluated by loading the motor to its rated load, with the supply maintained at rated voltage and rated frequency. The motor is run till thermally it reaches steady state, there-after the motor is switched off, the resistance of the stator winding is measured and compared with the winding resistance measured under cold conditions (before starting the test) to determine the temperature-rise of the motor.

A-1.2 Where large capacity motors are not possible to be evaluated, due to limitations in loading facilities, temperature-rise can be determined by superimposition method where by contribution of various electrical losses to winding temperature-rise is computed by tests to simulate the temperature-rise at rated load.

A-2 ESTIMATION OF LOSSES AND TEMPERATURE-RISE

A-2.1 Under rated conditions, the losses in the induction motor are:

a) Stray load loss in conductors;
b) Stray load loss in iron;
c) I^2R loss in stator windings;
d) I^2R loss in rotor windings; and
e) Frictional and windage loss.

All the losses except frictional and windage losses are electrical losses which may be designated as W_{0100}.

A-2.2 The temperature-rise of a motor may be given by the equation:

$$T = \frac{W_{0100}}{H \times A}$$

where

T = temperature-rise of stator windings, in ºC;

W_{0100} = total electrical losses, in watt ;

H = heat dissipation coefficient of the motor, in watt/m^2/ºC; and

A = surface area of the motor packet, in m^2.

A-2.3 For a given motor, *A* is constant. A series of tests can be carried out at speeds close to the rated speed thereby rendering *H* constant for all the tests. Therefore, if this series of tests is done in such a manner to simulate the electrical losses, the rated temperature-rise of the motor can be evaluated.

A-3 METHOD OF TESTING

A-3.1 The motor is run at no load with air gap voltage and rated frequency till steady state conditions are reached and the temperature-rise of winding is measured (T_1).

NOTES

1 The air gap voltage is the rated voltage minus the voltage drop due to stator leakage reactance for rated current.

2 The stator leakage reactance is calculated from designs.

A-3.2 The motor is now run at a reduced load, reduced voltage and rated frequency such that the rated input current is drawn by the motor till steady state conditions are reached and the temperature-rise of winding is measured (T_2).

A-3.3 The motor is now run at no load, with the same reduced voltage as given in **A-3.2** and rated frequency till steady state conditions are reached and temperature-rise of winding is measured (T_3).

A-4 EVALUATION

The temperature-rise of windings under rated conditions shall be:

$$T = T_1 + T_2 - T_3$$

ANNEX B

(*Clauses* 8.8.2.4.1 *and* 8.8.2.4.2)

TWO FREQUENCY EQUIVALENT LOADING METHOD FOR DETERMINATION OF TEMPERATURE-RISE OF INDUCTION MACHINES

B-1 INTRODUCTION

B-1.1 Load tests are carried out primarily to obtain temperature-rise of the machine under test. Direct coupled load test provides readings to determine various performance parameters for example efficiency, power factor, etc, conveniently and also to affirm general soundness of the machine. However, the requires load facility of similar capacity and mounting arrangement as of the motor under test for example 500 kW, 1 500 rpm, vertical, large machines are also required to be aligned properly to keep vibrations within safe required power from the supply, if regenerative loading system is not employed.

B-1.2 Investigations were carried out, therefore, on methods to get the desired results without the need to couple the machine on test to any external load. The result was the development of equivalent loading method by superimposition of two frequency supplies on the same machine under test. With this method, it is possible to load an induction machine to its rated load by using the main rated voltage and frequency supply along with an auxiliary generator delivering voltage at different frequency and without drawing rated power from the supply. With the consideration that large machines being produced in India in larger numbers, this test is being incorporated in this standard.

B-2 THEORY

When voltage is applied to an induction machine simultaneously from two sources in series, for example; with the connections as shown in Fig. 2, the resultant supply is a complex waveform which varies in amplitude and frequency at every instant. If the amplitude of main supply is rated voltage at 50 Hz, and voltage of the auxiliary supply is zero, the machine runs as a motor on no load near synchronous speed corresponding to 50 Hz supply. When auxiliary supply for example at 40 Hz is also superimposed, the complex rotating field generated by the interaction of two fields at different frequencies, tries to bring the speed down near to its synchronous speed. However, the machine cannot change its speed very fast due to its inertia and runs practically at a constant speed between 50 and 40 Hz synchronous speeds with oscillations.

For the given case, energy transfer to the rotor over a half cycle of the difference in the frequencies (for example 50 – 40 = 10 Hz) is positive and is negative over the next half cycle. Thus the power drawn for load over a full cycle is zero. In other words, in very second, the machine operates as a motor for 10 times then the complex supply frequency is more than the frequency corresponding to the running speed. It also runs as an induction generator for 10 times in a second when the complex frequency is less than the frequency corresponding to the running speed.

The amplitude of the current flow in the machine can be adjusted by changing the relative amplitudes of the two voltages and the frequency of the auxiliary source. Under such condition, only the losses of the machine are drawn from the supply sources.

The same effect is also possible by superimposing the auxiliary supply of different frequency on the rotor winding in case of wound rotor motors.

B-3 METHOD OF TESTING

One of the following two methods listed below shall be selected by the manufacturer depending on load facilities:

a) *Two frequency* — Primary superposition method; and
b) *Two frequency* — Secondary superposition method.

In addition, it is necessary to carry out tests and calculations as per Annex C, if the performance of the machine under test is required.

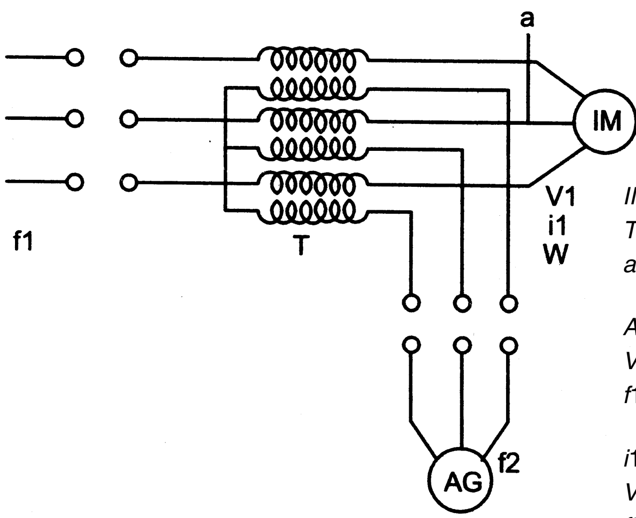
B-3.1 Two Frequency Primary Superposition Method

The connections are made as per Fig. 2. It is very important to have the same phase sequence of both the supply sources that is mains and auxiliary sources. This is ensured by running the test machine as a motor on each source individually and checking that the motor runs in the same direction. If it does not, the phases should be interchanged in one of the sources. It is also to be ensured that the test machine is run in the correct direction of rotation.

B-3.1.1 To start the test, the rated frequency supply (for example, 50 Hz in India) is applied first and the machine is run at rated voltage on no load. The generator of the auxiliary source is now run to the desired frequency (approximately 20 percent lower than main source frequency). Excitation to the generator of the auxiliary source is slowly increased to increase superimposed voltage and adjusted to pass the required current through the primary winding.

B-3.1.2 Generally, the auxiliary power source is adjusted so that the primary current is nearly equal to the rated value (current based method) and the total loss is measured and checked against expected nominal value at full load (calculated by Type equivalent circuit method). Heat run is continued, if the loss is found to determine temperature-rise.

If the loss is found higher, current is reduced to get the loss equal to the full load loss to I_{FLL} and heat run is carried out at mean of these two currents [that is Ieqv = $(I_{FL} + I_{FLL})/2$] to determine temperature-rise.



IM = induction machine to be tested.
T = series transformer.
a = connecting points of voltmeter ammeter, and voltmter.
Ag = generator as auxilliary power source.
V1 = terminal voltage (rated voltage).
f1 = frequency of main power supply (rated frequency).
i1 = primary current of inudction machine.
V2 = superposed voltage.
f2 = superposed voltage.
W = input watts.

FIG. 2 LOADING METHOD FOR INDUCTION MACHINES

CHARACTERISTIC CALCULATION BY CIRCLE DIAGRAM METHOD (L-TYPE EQUIVALENT CIRCUIT)

AS PER ANNEX C — R1 ALSO CONSIDERING 1.13 FACTOR FOR R AND ROTOR RESISTANCE R BASED ON R THAT IS EXTRAPOLATED AT F/50 DEEP BAR SINGLE CAE ROTOR

INDUCTION MOTOR SPECIFICATIONS

W.O. No.	1010/1
Customer	

kW	Volt	Hz	Poles
250	6600	50	4

Stator resistance (measured)

RY	YB	BR	at C
3.39000	3.39200	3.38800	32.9

Resistance (calculated)

R1	Convert Temperature	RT (75.115C)	R1/ph
3.39000	75	3.92273	1.96137

N.L. Characteristic

Hz	Vo		lo		Wo 1	Wo 2	Wo	Vo ph	lo ph
	1		1				1000		
50.10	6366.67	6366.7	8.79000	8.79	8.78	0.0	8780.0	3675.8	8.79

Locket Rotor Test

Sl No.	Hz	Vs		ls		Ws 1	Ws 2	Ws	Vs ph	ls ph
	—	60	Volts	12	Amps	Watts	Watts	0.5	Volts	Amps
1	50.0 0	27.0 0	1620. 0	2.346 7s	28.16	82.0	44.0	13680. 0	935.3 1	28.16
2	25.0 0	14.0 0	840.0	2.306 7	27.68	45.0	17.0	10080. 0	484.9 7	27.68
3	40.0 0	21.5 0	1290. 0	2.326 7	27.92	66.0	32.0	12240. 0	744.7 8	27.92
4	30.0 0	15.5 0	930.0	2.306 7	27.68	50.0	20.0	10800. 0	536.9 4	27.68

	Hz	Eq Impedance	Resistive Component	Reactive Component
		Zs'	Rs'	Xs'
1	50.00	33.214 0	5.750 4	32.712 5
2	25.00	17.520 7	4.385 4	16.96 3
3	40.00	26.675 6	5.2339 5	26.157 1
4	30.00	19.39 8	4.698 6	18.820 3

	Zs	Rs	Xs
Suffics	33.214	5.7504	32.7125
Suffics	17.5207	4.3854	16.963

Rs	Xs
3.07494	6.930854

FORECAST VALUES

10.00	3.5938	6.6195
1.00	3.1058	0.7759

Calculation Result

R	X	Z	ls	lsw	lsl	l0w	l0l	k	h	r
3.474 68	34.654 3	34.828	109.409	10.915 4	108.863	0.796 2	8.753 87	10.119 22	100.11	50.566 2

12s	tan α	α	cos α	sin α	K1	K2	tan β	β (deg)	β (rad)	tan (β /2)
100.62	9.893 02	84.228 1	0.100 57	0.994 93	5.211 25	4.907 97	19.210	87.020 13	1.518 79	0.949 3

Characteristics (By Circle Diagram Method)

Load	1	a	b	b1	b2	c2	t	11w	111
125 percent	27.337	47.560 6	8.641	0.869 0	8.597 4	0.421 5	27.758	29.002	17.351
100 percent	21.869 3	48.110 5	5.258	0.528 8	5.231 2	0.256 7	22.126	23.194	13.985
75 percent	16.402	48.660	2.848	0.286 4	2.833 21	0.138 9	16.541	17.485	11.587
50 percent	10.935	49.210 2	1.230	0.123 7	1.224 0	0.060 0	10.994 7	11.855	9.978
25 percent	5.467	49.76	0.301	0.030 3	0.299 7	0.014 7	5.482	6.293 83	9.054

Load	11	pf	η	S (percent)	P.O.T percent
125 percent	33.8	0.858	93.758	1.518	
100 percent	27.1	0.856	93.788	1.159	216.95
75 percent	21.0	0.834	93.308	0.840	
50 percent	15.5	0.765	91.740	0.546	
25 percent	11.0	0.571	86.368	0.268	

By IS 325 calculations 100% 26.93 0.87 93.78 0.86667 228.00 Test 1 @ 251 kW and 6540V 27.32

COMPARISION OF TEST RESULTS FOR INDUCTION MOTORS EQUIVALENT CIRCUIT AS PER ANNEX C MOTOR DETAILS (SQUIRREL CAGE ROTOR) — DEEP BAR SINGLE CAGE					
MACHINE No.		1010 — 1	SPEED (RPM)	1484	Info in column below showing
RATED VOLTAGE (V)		6 600	INSUL CLASS	F	High rotor resistance 5
RATED CURRENT (A)		28	FRAME	TPC355D	Showing very high slip compared to actual on direct loading method
RATED HP/kW		335/250	ENCLOSURE	CACA	
PERFORMANCE		IS 325	CIRCLE DIAGRAM METHOD L TYPE R at f/50		CIRCLE DIAGRAM METHOD L TYPE R at f/5
Pull Out Torque	(Percent FLT)	228.02	216.95		216.04
Efficiency (percent)	100	93.78	93.79		93.395
	75	93.78	93.31		93.033
	50	91.68	91.74		91.57
	25	—	86.37		86.295
Power Factor (percent)	100	0.87	0.86		0.857
	75	0.87	0.83		0.834
	50	0.79	0.77		0.765
	25	—	0.57		0.571
Current (A)	100	27.32	27.10		27.2
	75	21.24	21.00		21
	50	15.28	15.50		15.5
	25	—	11.00		11
Slip (Percent)	100	0.877	1.159		1.579
	75	0.675	0.840		1.142
	50	0.471	0.546		0.741
	25	—	0.27		0.364
TEMPERATURE-RISE TEST		Direct Coupled	Current Based	Loss Based	At mean current
Temperature-Rise	Stator	60.00	64.10	52.00	59.4
Temperature-Rise	Rotor	—	—	—	
Load Current	(A)	27.32	27.92	24.87	Current difference 10.9 percent to be contd….
Voltage	(V)	6540.00	6480.00	6480.00	Exhibiting deep bar effect
Input	(kW)	267.84	24.12	17.28	Test to be done at mean

NOTES

1 Operating frequency in rotor is the slip frequency which is nearest to *f*/50 for most motors of medium and large size. Therefore, actual current displacement effect in rotor under operating conditions is simulated by taking values of resistance corresponding to *f*/50 Hz.

Hence, values in last but one column provide more simulation to direct coupled load test values than *f*/5 tabulated in the last column.

2 Two frequency method imposes additional harmonic losses and hence temperature-rise at same current is higher than by direct coupled sinusoidal supply test.

Testing by 2 frequency method at full loss does not simulate the thermal profile properly, if there is as large difference between currents by direct testing and by loss based 2 frequency methods. Copper losses are lower in the latter resulting in lower temperature-rise of windings on test.

Hence a mean of currents calculated from current based and loss based methods is recommended.

B-3.2 Two Frequency Secondary Superposition Method

The connection are made as per Fig. 3. The sequence of phase rotation of the auxiliary supply fed to the secondary is required to be such that the machine rotates in the same direction when,

a) it is fed from primary with main source and secondary is short circuited; and
b) it is fed from secondary by the auxiliary source and primary is short circuited.

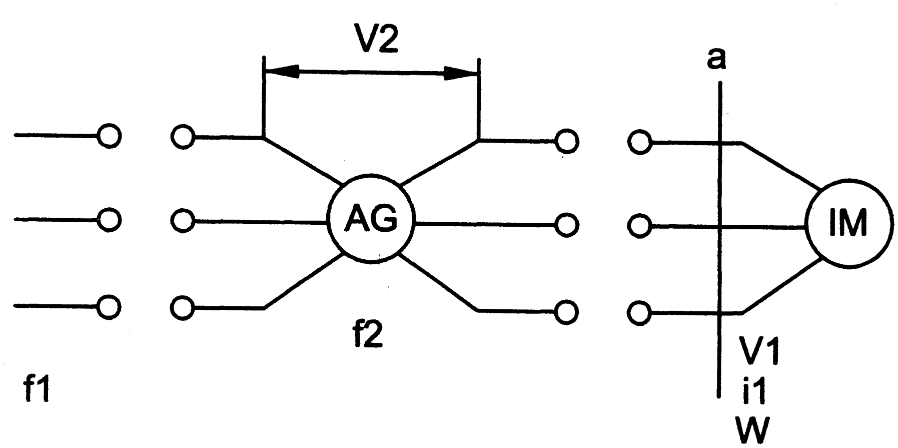
This is ensured by energizing one source at a time and running the machine as induction motor and checking that direction of rotation is correct and same in both the cases. Correct it, if necessary, by changing the phase sequence.

B-3.2.1 To start the test, main supply (for example 50 Hz in India) is applied first to the primary (stator) and the machine is run at rated voltage on no load. The generator of the auxiliary source is now run to the desired frequency (normally below half the frequency of the main source) at as low a frequency as possible and its output is fed to the secondary(wound rotor). Excitation to the generator of the auxiliary source is slowly increased to increase the superimposed voltage and adjusted to pass the required current through the primary winding.

B-3.2.2 Generally, the auxiliary power source is adjusted so that the primary current is nearly equal the rated value (current based method).

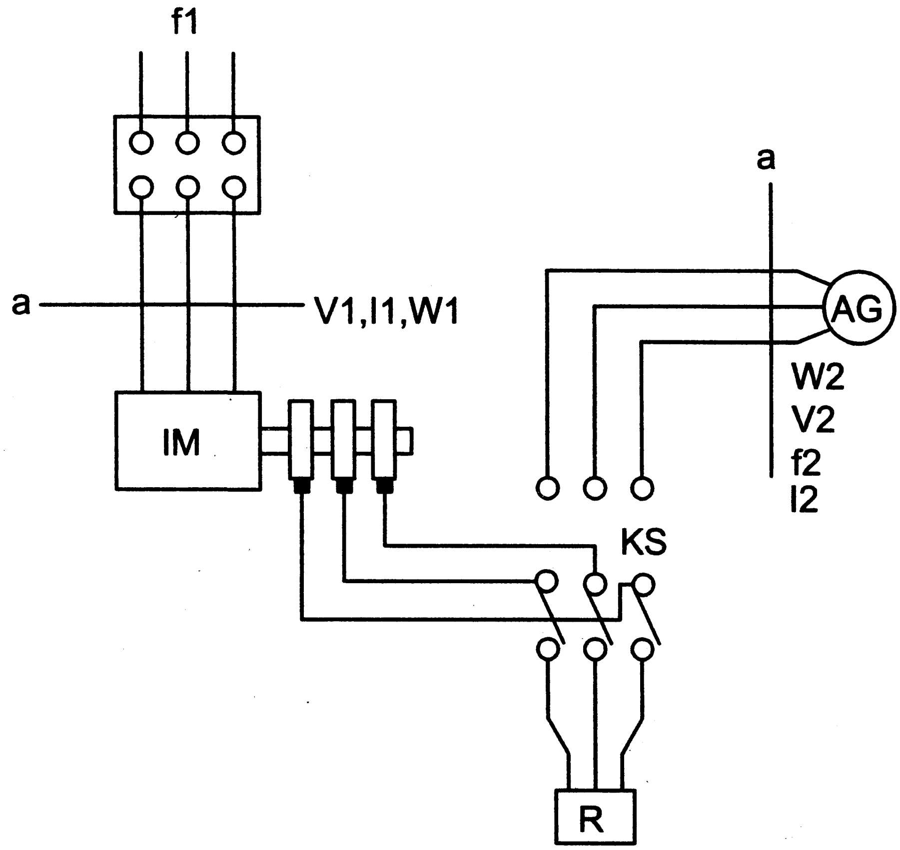
The testing is then conducted as per applicable this standard.

B-4 CONNECTION DIAGRAMS OF TWO FREQUENCY PRIMARY SUPERPOSED EQUIVALENT LOADING METHOD (*see* Fig. 4)



IM = induction machine to be tested.
T = series transformer.
a = connecting points of voltmeter, ammeter, and wattmeter.
AG = generator as auxiliary power source.
*V*1 = terminal voltage (rated voltage).
*f*1 = frequency of main power supply (rated frequency).
*i*1 = primary current of induction machine.
*V*2 = superposed voltage.
*f*2 = superposed frequency.
W = input watts.

FIG. 3 WITH USE OF TRANSFORMER IN SERIES



IM = induction machine to be tested.
a = connecting point of voltmeter, ammeter and wattmeter.
AG = generator as auxiliary power source.
*V*1 = terminal voltage [rated voltage].
*f*1 = frequency of power supply [rated frequency].
*I*1 = primary current of induction machine.
*I*2 = secondary current of induction machine.
*V*2 = superposed voltage.
*f*2 = superposed frequency.
*W*1 = primary input watts.
*W*2 = secondary input watts.
R = starting resistor.
KS = changeover switch.

FIG. 4 CONNECTION DIAGRAM OF TWO FREQUENCY SECONDARY SUPERPOSED EQUIVALENT LOADING METHOD

ANNEX C

(*Clauses* 8.8.3.3, 8.8.3.4, 8.8.4.5, 8.8.5, 8.8.5.5 *and* B-3)

PERFORMANCE DETERMINATION OF INDUCTION MACHINES BY CIRCLE DIAGRAM METHOD AND EQUIVALENT CIRCUIT METHOD

C-1 INTRODUCTION

Various performance figures on electrical machines are generally determined by taking readings on load in a test plant and computing the performance values from the same. However, when direct load tests are not carried out, it becomes necessary to determine the values by other methods. With the introduction of equivalent loading method in India, it has become necessary to have an acceptance standard for performance testing when induction machines are tested by these methods. The circle diagram method has been found to be one such method.

C-2 THEORY

During the development of induction machine theory, its equivalent circuit was developed on similar lines as of a transformer, with the secondary resistance replaced by a term r_2'/s. For various values of slip for an induction motor, the locus of the current vector forms a semi-circle. When operation is in generator mode is also considered, then the locus is a full circle.

Performance figures can be calculated either by taking values from an actual circle diagram drawn or by computing the values by trigonometric methods based on the circle diagram. Computations, eliminate errors in drawing the circle diagram, etc, and it can easily be cross checked using calculators/computers. This method is called circle diagram calculation method.

Normally, the type of equivalent circuit to be used in this standard is, L Type as shown in Fig. 5, and the circle diagram drawn for the same is shown in Fig. 6, which forms the basis for deriving the formulae for calculations.

When the motors are of special rotor type with substantial deep bar/double cage effect, the rotor resistance value under running conditions is much less than during locked rotor conditions. To account for such conditions, special Type L circuit diagram method has been evolved. This required additional locked rotor testing at reduced frequency.

To account for stray load losses, allowance of 0.5 percent has also been made in this standard in case of summation of losses method.

However, when the no load current is greater than 50 percent of rated full load current or 20 percent of the locked rotor current, this method is not preferred. In such case, the testing and calculation procedure should be as per the equivalent circuit method as described in **C-4.1**.

C-2.1 Circle Diagram Method

C-2.1.1 *Circle Diagram Method (Standard L Type)*

When each phase of a polyphase induction machine is expressed by the equivalent circuit as shown in Fig. 6, the circle diagram can be drawn as shown in Fig. 7. The procedure of drawing a circle diagram described in Fig. 7 is for information only, to understand the principles used in the calculations.

However, the calculation method described in **C-3**, should be followed as it is accurate and the errors in drawing the circle diagram are avoided.

The meanings of the various symbols is as shown below, with the figure for per phase quantities in star connection. Large machines are generally star connected and the procedure described below follows this assumption. For delta connected machines, appropriate factors are to be used to obtain correct per phase values.

For line to line quantities, the symbols used are as follows:

V_L = line to line voltage, in V.
I_L = line current, in A.
W_O = total no load input power, in W.
I_O = no load current at rated voltage, in A.
R = line to line resistance, in Ω.

C-2.2 Circle Diagram Method (Special L Type)

In special squirrel cage induction machines, that is induction machine having deep bar effect, r_2 and x_2 shown in Fig. 6, vary as function of slip s. Therefore, the total resistance and impedance referred to rated frequency are not constant. This relationship is shown in Fig. 7. In the limited range of slip from no load to breakdown torque, the characteristics can be calculated with sufficient accuracy on the assumption that r_2 and x_2 are constant.

The Type L circle diagram method based on this assumption and using their appropriate values is called the special Type L circle diagram method.

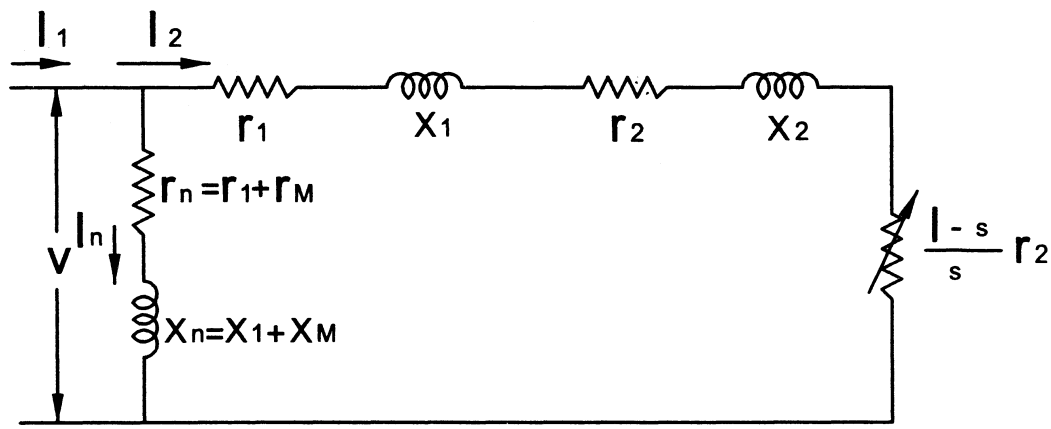
C-2.3 Drawing of Type L and special Type L circle diagram and calculations to obtain performance of induction motors (The whole procedure under this clause is for information only, to understand the principles, etc. The calculation method described in **C-3** is the only recognized method).

C-2.3.1 To draw the circle diagram, it is necessary to calculate the fundamental quantities which are specified in **C-3**.

C-2.3.2 To construct the circle diagram as shown in Fig. 7, draw a vertical line from the origin *ON*, and the take $ON' = I_{ow}$ and $OS' = I_{sw}$ on that line.

Draw two horizontal lines from *N′* and *S′* and take $N'N = I_{oi}$ and $S'S = I_{si}$ respectively on these lines.

From *S*, draw a vertical line *SU*, to the extension of *N′N*, connect *N* and *S* and draw a perpendicular line to *NS* at the point of bisection and let it intersect *NU* at *C*. Draw a semicircle with the centre at *C* and radius *CN* (this semicircle passes through *S*).



Circle diagram method

V = primary phase voltage.
I_1 = primary current.
I_2 = secondary current (referred to the primary).
I_n = no-load current.
I_M = magnetization current.
S = slip.

r_M = core loss resistance.
X_M = magnetizing reactance.
r_1 = resistance of primary winding.
r_2 = resistance of secondary winding (referred to the primary).
X_1 = leakage reactance of primary winding.
X_2 = leakage reactance of secondary winding. (referred to the primary).

FIG. 5 FREQUENCY

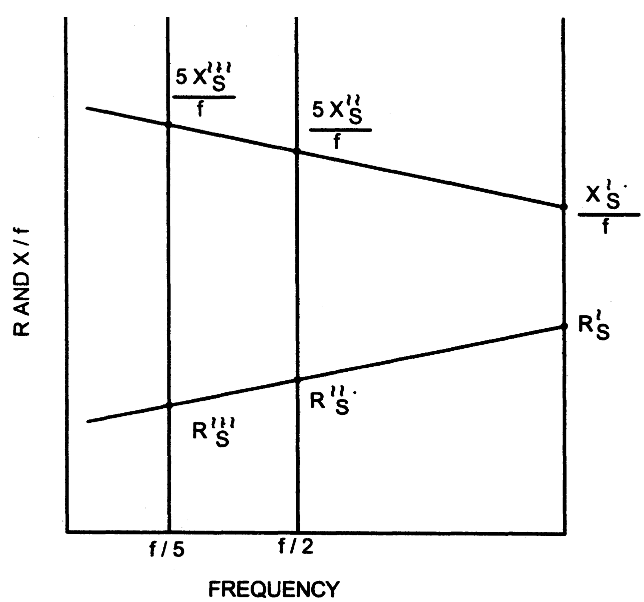


FIG. 6 TYPE L CIRCLE DIAGRAM

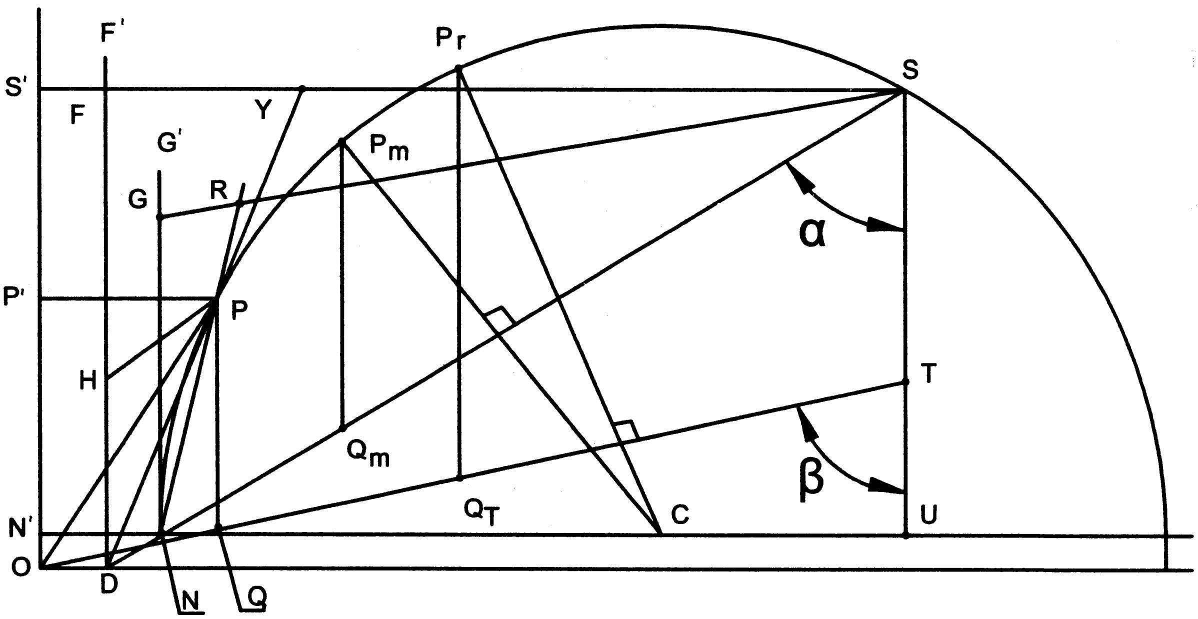


FIG. 7 TYPE L DIAGRAM

Measure $NS = I_2 s$ and take point T on SU so that

$$TU = \frac{\sqrt{3 \times I_2 s^2 x r_1}}{V_1}$$

And connect T and N.

Extend SN downwards to the left and make it intersect at D, the horizontal line drawn from the origin O.

Draw two vertical lines DF' and NG' from the points D and N respectively. Let the point of intersection of DF' and $S'S$ be F. Let the point of intersection of NG' and the line drawn parallel to NT from S be G.

From the centre C of the circle, draw two line perpendicular to NS and NT, and let the points of intersection of NG' and the line drawn parallel to NT from S be G.

From the centre C of the circle, draw two line perpendicular to NS and NT, and let the points of intersection of the extensions of these lines and the same circle be P_m and P_t respectively. Draw two vertical lines $P_m Q_m$ and $P_T Q_T$ from P_m and P_T respectively. (Q_m is the point on NS and Q_T is the point on NT).

C-2.3.3 While calculating performance by graphical method, for output P (W), for which characteristics are to be found, calculations are done as follows:

$$I = \frac{P}{\sqrt{3 \times V_1}}$$

and set a point H on DF' so that $DH = 1$,

Draw a line parallel to NS from H and let it intersect the semicircle at P (take the first point of intersection).

Draw a horizontal line from P and let it intersect OS' at P'. Connect P with O, D and N, and let the point of intersection of FS and the extension of DP be Y, and let the point of intersection of GS and the extension of NP be R. Draw a vertical line from P and let the point of intersection with NT be Q.

Characteristics for an output P (W):

Primary current: $I_1 = OP$

Power factor: $p_f = \frac{OP' \times 100}{OP}$ percent

Efficiency: $\pi = \frac{(1 - FY) \times 100 - 0.5}{FS}$ percent

Slip: $s = \frac{GR \times 100}{GS}$ percent

Torque: $\tau = \frac{\sqrt{3 \times V_1 \times PQ}}{1.027 \times N_s}$ kg.m

$= \frac{9.55 \times \sqrt{3 \times V_1 \times PQ}}{N_s}$ N.m

where

N_s = synchronous speed, in rpm

a) Maximum output $P_{\text{Max}} = \sqrt{3 \times V_1 \times P_m Q_m}$ W

b) Maximum torque $T_{\text{Max}} = \dfrac{\sqrt{3 \times V_1 \times P_T Q_T}}{1.027 \times N_s}$ kg.m

$$= \frac{9.55 \times \sqrt{3 \times V_1 \times P_T Q_T}}{N_s} \text{ N.m}$$

C-3 CALCULATION OF THE BASIC QUANTITIES FOR THREE-PHASE INDUCTION MACHINES

C-3.1 The following basic quantities shall be obtained to determine the characteristics by the circle diagram method on the basis of the equivalent circuit in Fig. 5.

C-3.1.1 *Resistance of Primary Winding*

The phase resistance of the primary windings (referred to star connection) at reference winding temperature is determined as follows:

$$R_1 = \frac{R_1}{2} \times \frac{(235+T)}{(235+t)} \quad \Omega \text{ for star connected machines}$$

$$= 1.5 \times R_1 \times \frac{(235+T)}{(235+t)} \quad \Omega \text{ for delta connected machines.}$$

where

R_1 = mean value of resistance (ohm) of primary indings measured between terminals;

t = temperature of windings when resistance is measured, in °C; and

T = reference winding temperature, in °C.

NOTE — T = 75°C for Class A and Class E temperature-rise limits, For Class B rise; T = 75°C at present (to be revised soon to 95°C with revision of this standard)

T = 115°C for Class F and Class H temperature limits.

C-3.1.2 *Real Part and Imaginary Part of no Load Current*

From rated voltage V_1, no load current I_o and no load input W_o in the no load test at the rated voltage and rated frequency, the following quantities are calculated:

Real part of l_o:

$$l_{ow} = \frac{W_o}{\sqrt{3 \times V_1}}$$

Imaginary part of I_o:

$$I_{oi} = \sqrt{I_o^2 - I_{ow}{}^2}$$

C-3.1.3 Real part and imaginary part of locked rotor current at reference winding temperature:

Locked rotor test is carried out at rated frequency f and at reduced supply voltage V_s' to obtain primary current I_s' close to rated current. Readings of these items and input W_s' are taken and the following quantities are calculated:

Equivalent impedance of one phase:

$$Z_s' = \frac{V_s'}{\sqrt{3 \times I_s'}} \quad \text{for star connected}$$

$$= \frac{\sqrt{3 \times V_s'}}{I_s'} \quad \text{for delta connected}$$

Resistance component of Z_s':

$$R_s' = \frac{W_s'}{3 \times I_s'^2} \quad \text{for star connected}$$

$$= \frac{W_s'}{I_s'^2} \quad \text{for delta connected}$$

Reactance component of Z_s':

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

C-3.1.4 *Procedure to Obtain Locked Rotor Parameters*

The procedure for determining locked rotor parameters varies depending upon the construction of the rotor and the following criteria and corresponding methods are used:

a) For shallow slot squirrel cage induction machines, small capacity wound rotor induction machines, intermediate capacity multipolar wound rotor induction machines and also medium capacity two pole wound-rotor type induction machines made with shallow strips. As the rotor is almost free from deep bar effect, there is practically no difference in rotor resistance at different frequencies. For these cases, locked rotor impedance Z at reference winding temperature is calculated as follows:

$R = R_s'$ (Classes A, E temperature-rise)

$R = 1.13 \times R_s'$ (Classes A, F and H temperature-rise)

$X = X_s'$

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

Current per phase I_s at locked rotor at rated voltage corresponding to this impedance is:

$$I_s = \frac{V_t}{\sqrt{3 \times Z}} \quad \text{for star connected}$$

Real part of $I_s : I_{sw} = I_s \times \frac{R}{Z}$

Imaginary part of $I_s : I_{si} = I_s \times \frac{X}{Z}$

Remark: Since $Z = Z'_s$ for Class A and Class E insulation, the following calculation may be carried out for these classes:

$$I_s = \frac{I'_s \times V_1}{V'_s}$$

$$W_s = \frac{W'_s (V_1)^2}{(V'_s)^2}$$

$$I_{sw} = \frac{W_s}{3 \times V_1} = \frac{W'_s \times V_1}{3 \times V'^2_S}$$

$$I_{si} = \sqrt{\left(I_s^2 - I_{sw}{}^2\right)}$$

b) For special squirrel cage induction machines that is with deep bar effect (Generally, all medium and large motors are of this type), intermediate capacity two pole induction machines with deep bar effect or large capacity wound rotor induction machines:

The machine shall be subjected to locked rotor test at ½ of rated frequency in addition to the locked rotor test at rated frequency. The following calculations are made:

From supply voltage V_s'' and input Wí, when current I close to rated current flows at locked rotor test at ½ of rated frequency:

$$Z_s\text{í} = \frac{V_s''}{\sqrt{3 \times I_s''}} \quad \text{for star connected}$$

$$R_s\text{í} = \frac{W_s''}{3 \times I_s''^2} \quad \text{for star connected}$$

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

Rsî and X_sî are obtained from Fig. 5 by using R_s', R_sí and, or from the following formulae:

R_sî = 1.6 × R_sí – 0.6 × R_s', where R_sî is the rotor resistance extrapolated at f/5 Hz.

X_sî = 1.6 × X_sí – 0.6 × X_s', where X_sî is the rotor resistance extrapolated at f/5 Hz.

However, when deep bar effect is high (for example as in the case of double cage, T bar, wedge bar, deep bar construction, etc), the rotor resistance shall be calculated at f/50 Hz which corresponds to 2 percent slip which is close to the normal operating slip for such machines to provide better accuracy on slip and efficiency calculations.

R_sî = 1.96 × R_sí – 0.96 × R_s' where R_sî is the rotor resistance extrapolated at f/50 Hz.

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

R = R_sî (or $R_s$íí as applicable): for Class A and Class E rise machines.

= 1.13 × R_sî (or R_sî as applicable): for Classes B, F and H rise machines.

X = 5 × X_sî = 3.2 × X_sí – 0.6 × X_sî

$$Z = \sqrt{\left(R^2 + X^2\right)}$$

Current I_s at locked rotor at rated voltage corresponding to this impedance is:

$$I_s = \frac{V_1}{\sqrt{3x}} \quad \text{for star connected}$$

Real part of $I_s : I_{sW} = I_s \times \frac{R}{Z}$

Imaginary part of $I_s : I_{si} = I_s \times \frac{X}{Z}$

C-3.2 Circle Diagram Calculation Method for Motors: For Standard as Well as for Special Type L Circle Diagram

The corresponding scalars on circle diagram are shown in Fig. 7 and the procedure adopted for drawing circle diagram described earlier in Fig. 7.

C-3.2.1 The procedure shall be as following with appropriate values taken for R, X, and Z used depending upon the standard L or special Type L as specified in **C-3.1.4**.

K = $SU = I_{sw} - I_{ow}$

H = $NU = I_{si} - I_{oi}$

p = NC (radius) = $\frac{1}{2} \times \left(h + \frac{K^2}{h}\right)$

$I_2 s$ = $NS = \sqrt{h^2 + k^2}$

α, cos α, sin α and tan (α/2) are determined from tan α = *h/k*

$$k_1 = TU = \frac{\sqrt{3 \times r_1 \times \left(h^2 + k^2\right)}}{V_1} \text{ for star connected}$$

$$4 \quad \frac{\sqrt{3 \times I_2 s^2 \times r_1}}{V_1}$$

$$k_2 = ST = k - k_1$$

β and tan (β/2) are determined from tan β = h/k_1

a) For and output *P* (W):

$$I = \frac{P}{\sqrt{3 \times V_1}}$$

$$a = \rho \sin\alpha - I\cos\alpha \equiv \frac{I_2 s}{2} - I\cos\alpha$$

$$b = \sqrt{a - \alpha^2 - I^2} \equiv \frac{I^2}{\left[a + \sqrt{\left(a^2 - I^2\right)}\right]}$$

$$b_1 = b\cos\alpha$$

$$b_2 = b\sin\alpha$$

$$c_2 = b_1 \times \frac{k_2}{k}$$

$$t = c_2 + I$$

$$I_{1w} = I_{ow} + b_1 + I$$

$$I_{1i} = I_{oi} + b_2$$

Primary current:

$$I_1 = \sqrt{\left(I_{1w}^{\ 2} + I_{1i}^{\ 2}\right)} \text{ A}$$

Power factor:

$$pf = \frac{I_{1w} \times 100}{I_1} \text{ Percent}$$

Efficiency :

$$\eta = \frac{I \times 100 - 0.5}{I_{1w}} \text{ Percent}$$

Slip:

$$s = \frac{c_2 \times 100}{T} \text{ Percent}$$

Torque:

$$\tau = \frac{\sqrt{3 \times V_1 \times t}}{1.027 \times N_s} \text{ kg.m}$$

$$= \frac{9.55 \times \sqrt{3 \times V_1 \times t}}{N_s} \text{ N.m}$$

b) Maximum output:

$$P_{Max} = \sqrt{3} \times V1 \times \rho \times \tan\left(\frac{\alpha}{2}\right) \text{ W}$$

c) Breakdown torque:

$$\tau_{Max} = \frac{\sqrt{3} \times V1 \times \rho \times \tan}{1.027 \times N_s}\left(\frac{\beta}{2}\right) \text{ kg.m}$$

C-3.3 Circle Diagram Method and Circle Diagram Calculation Method for Three-Phase Induction Generators

The whole procedure under this clause is for information only, to understand the principles, etc. The calculation method described in **C-3.3.2** is the only recognized method.

C-3.3.1 *Procedure to Draw Circle Diagram (for Information Only, to Understand Basis and Need not be Drawn to Calculate Performance)*

To construct the circle diagram as shown in Fig. 7, draw a vertical line from the origin *O*, and take $ON' = I_{ow}$ and $OS' = I_{sw}$ on that line. Draw two horizontal lines from *N′* and *S′* and take $N'N = I_{oi}$ and $S'S = I_{si}$ on these lines, respectively.

From *S*, draw a vertical line *SU*, to the extension of *N′*N, connect *N* and *S* and draw a perpendicular line to *NS* at the point of bisection and let it intersect *NU* at *C′*.

Measure $NS = I_2 s$ and take point *T* on SU so that,

$$TU = \frac{\sqrt{3 \times I_2 s^2 \times r_1}}{V_1}$$

and connect *T* and *N*.

Extend *SN* downwards to the left and make it intersect at *D*, the horizontal line drawn from the origin *O*. Draw two vertical lines *DF′* and *NG′* downwards from the points *D* and *N* respectively. Draw a vertical line downwards from the centre *C* of the circle, and let the point of intersection of the vertical line and extension of *OD* be Q_m, and that of the vertical line and the circle be P_m.

Through the centre *C* of the circle, draw a line perpendicular to *NT*, and let the point of intersection of the line and the lower semicircle be P_t.

From P_t, draw a vertical line and let the point of intersection of the vertical line and *NT* be Q_T.

For output P (W), for which characteristics are to be found, calculate

$$I = \frac{P}{\sqrt{3 \times V_1}}$$

and set a point H on DF' so that $DH = I$.

Draw a horizontal line from H and let it intersect the circle and P (take the first point of intersection) and the extension of $N'O$ at P'. Connect P with O, D and N.

Draw a vertical line from P and let it intersect NT at Q. Set a point J on SU so that $TJ = ST$ and connect J with N. Draw a line parallel to NT so that it intersects NP, and let the points of intersection of the line and NG', NP, NJ, be S_1', S_2', S_3' respectively.

Draw a line parallel to NS so that interests DP, and let the points of intersection of the line and DF', DP, extension of OD be Q_1,' Q_2,' Q_3' respectively.

From the drawing, characteristics are calculated in graphical method (not recognized in this standard) as follows:

a) Characteristics for an output P (W),

Primary current:

$$I_1 = OP$$

Power factor:

$$pf = \frac{OP' \times 100}{OP} \text{ Percent}$$

Efficiency:

$$\eta = \frac{Q_2' \, Q_3^3}{Q_1' \, Q_3'} \times 100 - 0.5 \text{ Percent}$$

Slip:

$$s = \frac{S_2' \, S_3' \times 100}{S_1' S_3'} \text{ Percent}$$

Torque:

$$\tau = \frac{\sqrt{3 \times V_1 \times PQ}}{1.027 \times N_s} \text{ kg.m}$$

$$= \frac{9.55 \times \sqrt{3 \times V_1 \times PQ}}{N_s} \text{ N.m}$$

where

N_s = synchronous speed, in rpm.

b) Maximum output:

$$P_{Max} = \sqrt{3 \times V_1 \times P_m \, Q_m} \text{ W}$$

c) Maximum torque:

$$\tau_{Max} = \frac{\sqrt{3 \times V_1 \times P_T Q_T}}{1.027 \times N_s} \text{ kg.m}$$

$$= \frac{9.55 \times \sqrt{3 \times V_1 \times P_T Q_T}}{N_s} \text{ N.m}$$

C-3.3.2 *Circle Diagram Calculation for Three Phase Induction Generators*

To calculate characteristics without drawing the circle diagram for an induction generator, use the following method which is the recognized method in this standard:

$$k = SU = I_{sw} - I_{ow}$$

$$h = NU = I_{si} - I_{oi}$$

$$p = NC \text{ (radius)} = \frac{1}{2} \times \left(h + \frac{K^2}{h} \right)$$

$$I_2 s = NS = \sqrt{h^2 + k^2}$$

α and cot α are determined from $\tan \alpha = \frac{h}{k}$

$$k_1 = TU = \frac{\sqrt{3 \times r_1 \times \left(h^2 + k^2\right)}}{V_1}$$

$$K_1 = \frac{\sqrt{3 \times I_2 s^2 \times r_1}}{V_1}$$

cosec β and cot β, are determined from $\tan \beta = \frac{h}{k}$

a) For an output P (W):

$$I = \frac{P}{\sqrt{3 \times V_1}}$$

$$b_2 = \rho - \sqrt{\left[\rho^2 - \left(I - I_{ow}\right)^2\right]}$$

$$b_1 = b^2 \tan (90° - \alpha) = b^2 \cot \alpha$$

$$c_2 = b_1 \times \frac{k_2}{k}$$

$$c_3 = b_1 \times \frac{k_1}{k}$$

$$t = I + I_{ow} + c_3$$

$$I_u = I_{oi} + b_2$$

Primary current:

$$I_1 = \sqrt{I^2 + I_u{}^2} \text{ A}$$

Power factor:

$$pf = \frac{I \times 100}{I_1} \text{ Percent}$$

Efficiency:

$$\eta = \frac{I \times 100 - 0.5}{\left(I + I_{ow} + b_1\right)} \text{ Percent}$$

Slip:

$$s = \frac{c_2 \times 100}{t} \text{ Percent}$$

Torque:

$$\tau = z\frac{\sqrt{3 \times V_1 \times t}}{1.027 \times N_s} \text{ kg.m}$$

$$= \frac{9.55 \times \sqrt{3 \times V_1 \times t}}{N_s} \text{ N.m}$$

b) Maximum output P_{Max}

$$= \sqrt{3 \times V_1 \times \left(\rho - I_{ow}\right)} \text{ W}$$

c) Maximum torque τ_{Max}

$$= \frac{\sqrt{3 \times V_1 \times \rho \times \left(\text{cosec } \beta + \cot \beta\right)}}{1.027 \times N_s} \text{ kg.m}$$

$$= \frac{9.55 \times \sqrt{3 \times V_1 \times \rho \times \left(\text{cosec } \beta + \cot \beta\right)}}{N_s} \text{ N.m}$$

NOTE — The corresponding scalars on circle diagram are shown in Fig. 8 and the procedure adopted for drawing circle diagram is described in **C-2.3.1**.

C-4 EQUIVALENT CIRCUIT METHOD

C-4.1 The equivalent circuit method is used to determine the characteristics of induction machines by calculation on the basis that Type T equivalent circuit as shown in Fig. 9 is applicable for three-phase induction machines. This circuit is better suited when magnetization currents are high.

In the case of special squirrel cage motors r_2 and x_2 in the current are functions of slip, s. However, in the limited range of slip from no load to the maximum torque, r_2 and x_2 can be regarded as constant irrespective of slip. Leakage reactances x_1 and x_2 become the function of current in the range of large currents, so the values x_1 and x_2 become the function of current in the range of large currents, so the values x_1 and x_2 to calculate maximum output and break down torque are obtained from the result of the locked rotor test carried out at nearly twice the rated current.

The characteristics are calculated after the circuit in Fig. 9 is transformed to the circuit in Fig. 9. The relationship between the constants of the circuit in Fig. 9 and those in Fig. 9 are as follows:

$$r_{1t} + j\text{x}_{1t} = M^{-1}\,(r_1 + j\text{x}_1) + M^{-2} j\text{x}_2$$

$$r_{2t} + j\text{x}_{2t} = M^{-2}\, r_2$$

where

$$M = \frac{\left(r_M + jx_M\right)}{\left[r_1 + r_M + j\left(x_1 + x_M\right)\right]}$$

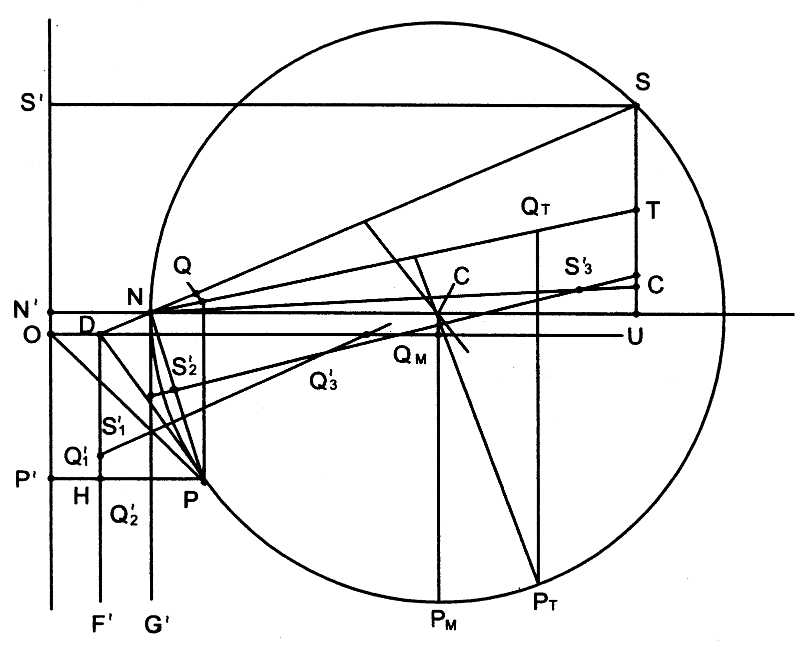


FIG. 8 CIRCLE DIAGRAM

CIRCLE DIAGRAM METHOD

V = primary star phase voltage.

I_1 = primary current.

I_2 = secondary current (referred to the primary).

I_n = non-load current.

I_M = exciting current

s = slip

r_M = core loss resistance

X_M = magnetizing reactance.

r_1 = resistance of primary winding.

r_2 = resistance of secondary winding (referred

X_1 = leakage reactance of primary winding.

X_2 = leakage reactance of secondary winding (referred to the primary)

C-4.2 Calculation of the Fundamental Quantities

C-4.2.1 *Resistance of Primary Windings*

The primary resistance r_1 per phase corrected to the reference winding temperature (star converted value) shall be calculated in accordance with **C-2.1.1**.

C-4.2.2 *Quantities to be Obtained from no Load Test*

The machine shall be operated at no load with voltage applied at rated frequency. The primary voltage, primary current and input power shall be measured at several points of primary voltage which is gradually reduced from a voltage slightly higher than the rated voltage to a voltage which can hold the machine to rotate around the synchronous speed.

a) The curve representing the relation between input power and voltage is extended to zero voltage (V) to obtain mechanical losses W_m (W).

b) The following calculation is carried out from primary current I_o (A) and input power W_o (W) at the rated voltage V_1 (V). The no-load impedance (resistance component r_n and reactance component x_n) under the assumption of no mechanical losses and the core loss resistance r_M are obtained:

$$I_{ow} = \frac{W_o}{\sqrt{3 \times V_1}}$$

$$I_{oi} = \sqrt{I_o^{\ 2} - I_{ow}^{\ 2}}$$

$$I_{nw} = \frac{(W_o - W_m)}{\sqrt{3 \times V_1}}$$

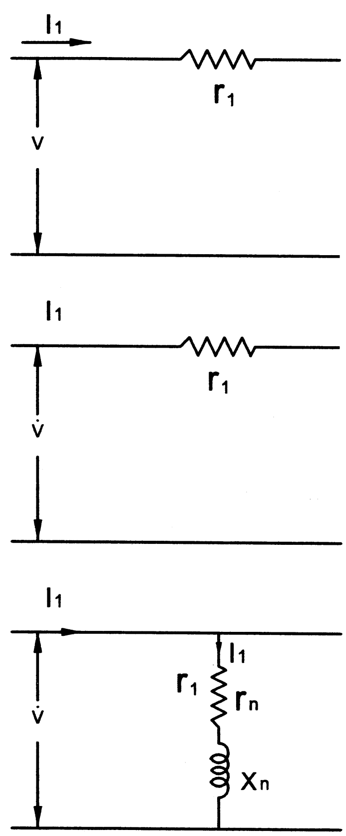


FIG. 9 TYPE T EQUIVALENT CIRCUIT

$$I_{ni} = I_{oi}$$

$$g_n = \frac{\sqrt{3 \times I_{nw}}}{V_1}$$

$$b_n = \frac{\sqrt{3 \times I_{nw}}}{V_1}$$

$$r_n = \frac{g_n}{g_n^{\ 2} + b_n^{\ 2}}$$

$$x_n = \frac{b_\sigma}{g_o^{\ 2} + b_o^{\ 2}}$$

$$r_M = r_n - r_1$$

c) Calculation is carried out in the same manner as (b), from primary current I_o' (A) and input power W_o'(W) at V_1'(V) at approximately 60 ~ 70 percent of the rated voltage in order to obtain the unsaturated value x_n' of reactance component of no-load impedance.

C-4.2.3 *Quantities to be Obtained from Locked Rotor Test*

C-4.2.3.1 *Rated frequency lock rotor test*

a) *Near rated current*

The locked rotor test shall be carried out with a current almost equal to the rated current, and the primary voltage V_s' (V), Primary current I_s' (A) and input power W_s' (W) are measured. From this result, the following calculation is done:

$$R_{2L'} = \frac{W_{s'} - r_{1L}}{3 \times I_{s'}^{\ 2}}$$

$$X_{L'} = \sqrt{V_s^{'} \Big/ \sqrt{3 \times I_{s'}^2 - \left(W_{s'} / 3 \times I_{s'}^2\right)^2}}$$

$$X_1 = \frac{X'_{L'}}{2}$$

$$x_M = x_n - x_1$$

$$x_{M'} = x_{n'} - x_1$$

where r_{1L} is the primary resistance per phase (star converted value) at the temperature during the locked rotor test.

Using the above values, secondary resistance, r_2' and secondary leakage reactance, x_2' for slip 1.0 are obtained by the following calculation:

$$X_{2L}' = X_1$$

$$g_3' = \frac{R_{21}'}{\left(R_{2L}'^{\,2} + X_{2L}'^{\,2}\right)}$$

$$b_3' = \frac{X_{21}'}{\left(R_{2L}'^{\,2} + X_{2L}'^{\,2}\right)}$$

$$g_M' = \frac{r_M}{\left(r_M^{\ 2} + x_M'^{\,2}\right)}$$

$$b_M' = \frac{x_M'}{\left(r_M^{\ 2} + x_M'^{\,2}\right)}$$

$$g_2' = g_3' - g_M'$$

$$b_2' = b_3' - b_M'$$

$$r_2' = \frac{g_2'}{\left(g_2'^{\,2} + b_2'^{\,2}\right)}$$

$$x_2' = \frac{b_2'}{\left(g_2'^{\,2} + b_2'^{\,2}\right)}$$

b) *Near twice rated current*

To determine maximum output and breakdown torque, a locked rotor test shall be carried out with a current equal to nearly twice the rated current, and primary voltage V_sî (V), primary current I_sî (A) and input power W_sî (W), shall be measured. Using these values, instead of the above V_s', I_s', and W_s', calculation is carried out in the same manner as above and the values x_{1m}, r_2î and x_2î for the current nearly twice the rated current are obtained corresponding to x_1, r_2' and x_2', with the exception that the values of x_M and $x_{M'}$ in this calculation should be the values which are obtained from the result of the locked rotor test at current almost equal to the rated current.

C-4.2.3.2 *Low frequency locked rotor test*

a) *Near rated current*

The locked rotor test shall be carried out with the current almost equal to the rated current at a frequency of around 25 percent of the rated frequency. Primary voltage V_sí (V), primary current I_sí (A) and input power W_sí (W) shall be measured. The following calculation is carried out from this result:

$$R_{2L}\text{í} = \frac{W_s'' - \Upsilon_{1L}}{3 \times I_s''^2}$$

$$X_L\text{í} = \sqrt{\left(V_s'' / \sqrt{3 \times I_s''}\right)^2 - \left(w_s'' / 3 \times I_s''\right)^2}$$

If the ratio of frequency in this test (f_L) and the rated frequency (f_R) is K ($=f_L/f_R$), the secondary resistance, r_2í and the secondary leakage reactance, x_2í when the slip is equal to k are obtained by the following calculation:

$$X_{2L}\text{í} = X_L\text{í} - k \times x_1$$

$$g_3\text{í} = \frac{R_{2L}''}{\left(R_{2L}''^2 + X_{2L}''^2\right)}$$

$$b_3\text{í} = \frac{X_{2L}''}{\left(R_{2L}''^2 + X_{2L}''^2\right)}$$

$$b_M\text{í} = \frac{1}{k \times x_M'}$$

$$b_2\text{í} = b_3\text{í} - b_M\text{í}$$

$$r_2\text{í} = \frac{g_3''}{\left(g_3''^2 + X_2''^2\right)}$$

$$g_2\text{í} = \frac{1}{k} \times \frac{b_2''}{\left(g_3''^2 \; b_2''^2\right)}$$

b) *Near twice rated current*

For calculation of maximum output and breakdown torque, a locked rotor test shall be carried out at low frequency with a current nearly twice the rated current, and primary voltage V_sí (V), primary current I_sí (A) and input power W_sí (W) are measured. Using these instead of V_s', I_s', and W_s', the same calculation as above is made and the values $r_2$íí and xí$_2$í and for the current nearly twice the rated current corresponding to r_2í and x_2í are obtained.

C-4.3 Determination of Constants at Operation

Secondary resistance r_2 and secondary leakage reactance x_2 at operation (slip ≈ 0) are obtained by the following calculation:

$$h = \frac{\left(x_2'' - x_2'\right)}{\left(r_2' - r_2''\right)}$$

In the case of $h > 1.0$

$$m = \frac{k^2 \times \left(1 + h^2\right)}{\left(1 + k^2\right)}$$

$$r_2 = \left[r_2'' - m \times \left(r_2' - r_2''\right)\right] \times \frac{r_1}{r_{1L}}$$

$$x_2 = x_2\text{í} - m \times (x_2\text{í} - x_2')$$

In the case of $h \leq 1.0$

$$r_2 = \left[r_2' - \frac{4}{5} \times \frac{\left(r_2' - r_2''\right)}{(1-k)}\right] \times \frac{r_1}{r_{1L}}$$

$$x_2 = \left[x_2' - \frac{4}{5} \times \frac{\left(x_2'' - x_2'\right)}{(1-k)}\right]$$

Further calculation is carried out in the same manner as above using the values r_2î, x_2î, $r_2$íí and $x_2$íí at a current equal to nearly twice the rated current instead of r_2', x_2', r_2'' and x_2'' in order to obtain the values r_{2m} and x_{2m} corresponding to r_2 and x_2.

C-4.4 Determination of Constants for the Determination of Characteristics

Constants in the Type T equivalent circuit obtained above shall be converted to the constants of the equivalent circuit in Fig. 9. First of all, the expression $M^{-1} = d_1 - jd_2$ is assumed, and d_1 and d_2 are calculated by the following formula:

$$d_1 = \frac{1 + \left(r_1 \times r_M + x_1 \times x_M\right)}{\left(r_M^2 + x_M^2\right)}$$

$$d_2 = \frac{\left(r_1 \times x_M - r_M \times x_1\right)}{\left(r_M^2 + x_M^2\right)}$$

Constants for the calculation of characteristics are obtained by the following formula:

$R_{1t} = d_1 \times r_1 + d_2 \times x_1 + 2d_1 \times d_2 \times x_2$

$x_{1t} = -d_2 \times r_1 + d_1 \times x_1 + (d_1^2 - d_2^2) \times x_2$

$r_{2t} = (d_1^2 - d_2^2) \times r_2$

$x_{2t} = -2d_1 \times d_2 \times r_2$

Moreover, constants for current equal to nearly twice the rated current shall be calculated similarly and values r_{1tm}, x_{1tm}, r_{2tm} and x_{2tm} corresponding to r_{1t}, x_{1t}, r_{2t}, x_{2t} are obtained.

C-4.5 Determination of Characteristics

C-4.5.1 *Additional Load Losses — Stray Load Losses*

The value of additional load loses G at an output P (W) is obtained by the following formula:

$$G = 0.005 \times \frac{P^2}{P_R} \text{ W}$$

where

P_R = rated power, in Watt.

C-4.5.2 *Calculation of Slip*

a) Slip s for the output P (W):

$$s = \frac{2c}{\left[b + \left(b^2 - 4ac\right)^{1/2}\right]}$$

where

$c = r_{2t}^2 + x_{2t}^2$

$$b = \frac{V_1^2 \times \sqrt{C}}{(P + W_m + G)} - 2\,(r_{1t} \times r_{2t} + x_{1t}\, x_{2t})$$

b) Slip s_p at which maximum output occurs:

$$s_p = \frac{\left(r_{2tm^2} + x_{2tm^2}\right)^{1/2}}{\left[\left(r_{2tm^2} + x_{2tm^2}\right)^2 + \left(r_{1tm} + r_{2tm}\right)^2 + \left(x_{1tm} + x_{2tm}\right)^2\right]^{-1/2}}$$

c) Slip s_t at which maximum torque occurs:

$$s_t = \frac{\left(r_{2tm}^{\ 2} + x_{2tm}^{\ 2}\right)^{1/2}}{\left(r_{1tm}^{\ 2} + x_{1tm}^{\ 2}\right)^{1/2}}$$

C-4.5.3 *Characteristics for the Output P (*W*):*

$$V = \frac{V_1}{\sqrt{3}}$$

$R = r_{1t} + (r_{2t}/s)$

$X = x_{1t} + (x_{2t}/s)$

$$I_{tw} = \frac{R \times V}{\left(R^2 + X^2\right)}$$

$$I_{ti} = \frac{R \times V}{\left(R^2 + X^2\right)}$$

Primary current:

$$I_1 = \sqrt{\left(I_{nw} + I_{tw}\right)^2 + \left(I_{ni} + I_{ti}\right)^2}$$

Power factor:

$$pf = \frac{\left(I_{nw} + I_{tw}\right)}{I_1} \times 100 \text{ Percent}$$

Efficiency:

$$\eta = \frac{P}{\sqrt{3 \times V_1 \times \left(I_{nw} + I_{tw}\right)}} \times 100 \text{ Percent}$$

Torque:

$$\tau = \frac{P}{1.027 \times (1 - s) \times N_s} \text{ kg.m}$$

$$= 9.55 \times \frac{P}{(1 - s) \times N_s} \text{ N.m}$$

where

N_s =synchronous speed, in rpm.

C-4.5.4 *Maximum Output* P_{Max}

$$R_p = r_{1tm} + \frac{r_{2tm}}{S_p}$$

$$X_p = x_{1tm} + \frac{x_{2tm}}{S_p}$$

$$I_{tpw} = \frac{R_p}{\left(R_p^2 + X_p^2\right)} \times V$$

$$I_{tpi} = \frac{X_p}{\left(R_p^2 + X_p^2\right)} \times V$$

$I_{tp}^2 = I_{tpw2} + I_{tpi}^2$

$$P_{Max} = 3 \times \left(\frac{1 - s_p}{s_p}\right) \times I_{tp}^{\ 2} \times \sqrt{\left(r_{2tm}^{\ 2} + x_{2tm}^{\ 2}\right)} \text{ W}$$

C-4.5.5 *Breakdown Torque,* τ_{Max}

$$R_\tau = x_{1tm} + \frac{r_{2tm}}{s_t}$$

$$X_\tau = x_{1tm} + \frac{x_{2tm}}{s_t}$$

$$I_{t\tau w} = \frac{R_r}{\left(R_r^2 + X_r^2\right)} \times V$$

$$I_{t\tau i} = \frac{X_r}{\left(R_r^2 + X_r^2\right)} \times V$$

$$I_{t\tau}{}^2 = I_{tp\tau w}{}^2 + I_{t\tau i}{}^2$$

$$P_2 = 3 \times \left(\frac{1 - s_t}{s_t}\right) \times I_{t\tau}{}^2 \times \sqrt{\left(r_{2tm}{}^2 + x_{2tm}{}^2\right)} \text{ W}$$

$$\tau_{Max} = \frac{P_2}{1.027 \times N_2} \text{ kg.m.}$$

$$= 9.55 \times \frac{P_2}{N_2} \text{ N.m}$$

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