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(Revision of IEEE Std 252-1977)

IEEE Standard Test Procedure for Polyphase Induction Motors Having Liquid in the Magnetic Gap

Sponsor
Electric Machinery Committee
of the
IEEE Power Engineering Society

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Abstract: Instructions for conducting and reporting the more generally applicable and acceptable tests to determine the performance characteristics of polyphase induction motors having liquid in the magnetic gap are given. Constants in several equations and forms apply to three-phase motors only and require modification for application to motors having another number of phases. It is not intended that the procedure cover all possible tests or tests of a research nature. The procedure shall not be interpreted as requiring the making of any or all of the tests described herein in any given transaction.
Keywords: liquid in the magnetic gap, polyphase induction motor, test procedures, three-phase motor

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Introduction

(This introduction is not part of IEEE Std 252-1995, IEEE Standard Test Procedure for Polyphase Induction Motors Having Liquid in the Magnetic Gap.)

In recent years, induction motors have found increasing usage in applications where the rotor operates in a liquid environment. Frequent applications include driving pumps in primary coolant loops in nuclear reactors, in boiler forced circulating systems, and in deep well pumping. From the viewpoint of testing and test procedures, motors designed for these applications differ from more conventional motors principally in having additional loss due to circulating currents in the metallic barriers in the air gap, in having higher friction loss, and in reduced accessibility to the windings and rotating parts. Because of these differences and the increasing usage of such motors, the Induction Machinery Subcommittee of the Rotating Machinery Committee undertook the preparation of this test procedure, which was derived from AIEE Std 500 (now IEEE Std 112-1991, IEEE Standard Test Procedure for Polyphase Induction Motors and Generators).

The Institute wishes to acknowledge its indebtedness to those who have so freely given of their time and knowledge, and have conducted experimental work on which many of the IEEE publications are based.

At the time this test procedure was originally approved, a working group of the Induction Machinery Subcommittee of the Electric Machinery Committee had the following membership:

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IEEE Standard Test Procedure for Polyphase Induction Motors Having Liquid in the Magnetic Gap

1. Scope

This test procedure covers instructions for conducting and reporting the more generally applicable and acceptable tests to determine the performance characteristics of polyphase induction motors having liquid in the magnetic gap. Constants in several equations and forms apply to three-phase motors only and require modification for application to motors having another number of phases. It is not intended that the procedure cover all possible tests or tests of a research nature. The procedure shall not be interpreted as requiring the making of any or all of the tests described herein in any given transaction.

Test report forms are provided with this standard. For the convenience of the user, they are organized into a normative annex.

2. References

This standard shall be used in conjunction with the following references:

IEEE Std 4-1995, IEEE Standard Techniques for High-Voltage Testing (ANSI).[1]

IEEE Std 43-1974 (Reaff 1991), IEEE Recommended Practice for Testing Insulation Resistance of Rotating Machinery (ANSI).

IEEE Std 85-1973 (Reaff 1986), IEEE Standard Test Procedure for Airborne Sound Measurements on Rotating Electric Machinery (ANSI).

IEEE Std 112-1991, IEEE Standard Test Procedure for Polyphase Induction Motors and Generators (ANSI).

IEEE Std 118-1978 (Reaff 1992), IEEE Standard Test Code for Resistance Measurements (ANSI).

IEEE Std 119-1974, IEEE Recommended Practice for General Principles of Temperature Measurement as Applied to Electrical Apparatus.[2]

IEEE Std 120-1989, IEEE Master Test Guide for Electrical Measurements in Power Circuits (ANSI).

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[1] IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA.

[2] IEEE Std 119-1974 has been withdrawn; however, copies can be obtained from Global Engineering, 15 Inverness Way East, Englewood, CO 80112-5704, USA, tel. (303) 792-2181.

3. General

3.1 Kinds of tests

These motors are normally given either a routine test or a complete test.

3.1.1 Routine test

The routine test includes measurement of speed, power input, and current input at no load, rated voltage and frequency; power input and current input with locked rotor; and, winding resistance, insulation resistance, and dielectric test. The locked rotor test may also be performed with single-phase power applied to the motor. Form 1 may be used for reporting such data.

3.1.2 Complete test

The complete test includes a routine test plus additional tests necessary to determine efficiency, power factor, starting torque, breakdown torque, rated-load slip, and rated-load temperature rise.

Form 2 may be used for reporting such data. Additional tests, such as measurement of noise, vibration, and speed-torque characteristics that are described in this test procedure, and other tests, such as measurement of shaft currents that are not covered in this test procedure, may be used.

3.2 Choice of test

A complete list of tests covered by this procedure is given in the contents. Alternate methods are described for making many of the tests. In some cases the preferred method is indicated.

3.3 Cautions

Many IEEE and ANSI standards are referenced in this document. The standards referenced will be those in effect when this revision is approved. Users are cautioned to carefully review the history of old machines with respect to IEEE and ANSI standards in effect at the time when they were manufactured.

4. Electrical measurements

4.1 General

Electrical measurements shall be made in accordance with IEEE Std 120-1989.[3]

4.2 Power supply

The supply voltage shall closely approach sine-wave form and shall provide balanced phase voltages. The voltage waveform deviation shall not exceed 10%. The frequency shall be closely regulated and shall be measured within an accuracy of 0.1% of rated value.

4.3 Instrument selection

The instruments used in electrical measurements shall be selected to give indications well up on the scale, i.e., where a fraction of a division is easily estimated and where such a fraction is a small percentage of the value read. The indicating instruments shall bear record of calibration within 12 months of the test, indicating limits of error no greater than ± 0.5% of full scale.

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[3] Information about references can be found in clause 2.

4.4 Instrument transformers

When current and voltage instrument transformers are used, corrections shall be made for ratio errors in voltage and current measurements and for ratio and phase-angle errors in power measurements. The errors of the instrument transformers shall not be greater than 0.5%.

4.5 Voltage

The phase voltages shall be read at the motor terminals. The arithmetic average of the root-mean-square phase voltages shall be used in calculating machine characteristics.

4.6 Current

The line currents to each phase shall be measured. The arithmetic average of the root-mean-square line currents shall be used in calculating machine characteristics.

4.7 Power

The average power input to a three-phase machine shall be measured by three single-phase wattmeters connected in Y as in the three-wattmeter method, or by two single-phase wattmeters connected as in the two-wattmeter method, or by a single polyphase wattmeter. Correction shall be made for instrument losses.

5. Performance determination[4]

5.1 Temperature

Precautions shall be taken that the internal coolant approximates the design temperature. All performance determinations shall be corrected to a temperature corresponding to the rated temperature of the supplied coolant.

5.2 Pressure

Some designs may require pressurization of the internal coolant for safe operation. In these cases, safety measures appropriate to the design should be exercised.

5.3 Efficiency

Efficiency is the ratio of output power to input power. Unless otherwise specified, the efficiency shall be determined for rated voltage, frequency, and coolant temperature and flow.

5.3.1 Measurements

Readings of power input, current, voltage, frequency, slip, torque, temperature, coolant flow where applicable, and stator coil maximum winding surface temperature or stator winding resistance, shall be obtained for six load points approximately equally spaced from one-quarter (0.25) to one and one-half (1.5) times rated load.

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[4] See Form 5 for nomenclature.

5.3.2 Mechanical-output measurement methods

In all mechanical-output measurement method tests, the electrical and mechanical power are measured directly. Performance of a machine may be calculated as shown on Form 3. The output power is calculated as follows:

$$W = K_1 \cdot n \cdot T$$

where

W	is output power, in W
T	is torque
K_1	is 0.142 if T is in lb·ft
K_1	is 0.1047 if T is in N·m
n	is speed, in r/min

Torque corrections appropriate to the equipment used shall be made.

5.3.2.1 Brake

The *tare* (any locking beam or brake apparatus required for the test, but not part of the complete assembled motor), if present, shall be determined and compensated.

5.3.2.2 Dynamometer

The dynamometer rating should not exceed three (3) times the machine rating, and it should be sensitive to a change of torque of 0.25% of the rated torque.

5.3.3 Segregated-loss methods

The input shall be measured as indicated in 5.3.3.1 or calculated as described in 5.3.3.2. The output shall be determined by subtracting the losses from the input. An induction machine having liquid in the magnetic gap has, or may have, the losses shown in table 1.

Table 1—Losses in machines having liquid in the magnetic gap

Loss designation	Description
Friction and fluid loss	Mechanical loss due to rotation of rotor assembly in its normal environment
Iron core loss	Loss in iron at no load
Can loss[a]	Loss in cans at no load
Stator I^2R loss	Loss in stator windings
Rotor I^2R loss	Loss in rotor windings
Stray-load loss	Load-dependent loss in iron, rotor, and stator cans, and eddy current and high-frequency losses in conductors

[a] The term *can* in this standard refers to a protective cylinder at the stator inside diameter (ID) and/or the rotor outside diameter (OD) that may or may not be an electrically conductive material.

5.3.3.1 Input measurements

To obtain the required data, it is necessary to couple, belt, or gear the machine to a variable load.

The required data are as follows:

a) Stator resistance
b) No-load current and no-load losses
c) Rotor slip
d) Maximum stator winding surface temperature or stator resistance
e) Watts input
f) Line current
g) Stray-load loss

Data shall be obtained for six load points approximately equally spaced from one-quarter (0.25) to one and one-half (1.5) times rated load.

Forms 4 and 6 may be used for calculating and tabulating the performance.

5.3.3.2 Equivalent-circuit calculations

When tests under load cannot be made, operating characteristics may be calculated from the equivalent circuit (see figure 1). Required constants should be calculated from the no-load, impedance, and stray-load loss data using formulas on Form 5 and may be recorded on Form 6. Form 7 is a worksheet upon which the circuit calculations may be made.

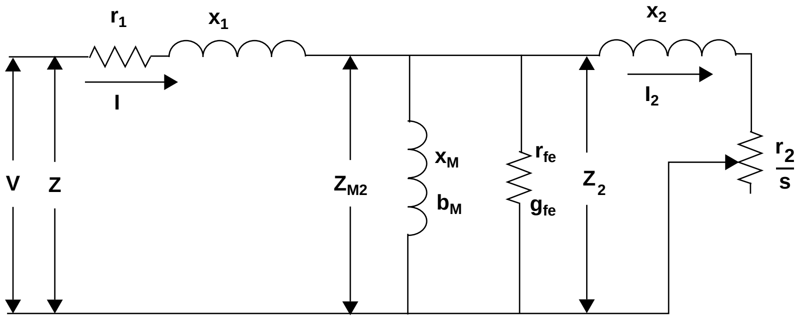

Figure 1—Equivalent circuit

The results of the equivalent circuit calculations may be summarized on Form 6.

Rotor resistance and reactance may vary considerably with rotor frequency, hence with rotor speed. The values of r_2 and x_2 used in equivalent circuit calculations may be calculated from an impedance test (see 5.9.3). An alternate method of obtaining r_2 is described below.

Form 5 is arranged on the basis of x_1 and x_2 remaining constant throughout the range of operation on the machine. If the impedance curve of current versus volts departs from a straight line in the range of currents under consideration, the values of reactance corresponding to each value of I shall be used in each column of Form 7.

When a test curve of motor slip versus line current under load is available, r_2 should be determined by the following procedure. Calculate I by solving the equivalent circuit (Form 7) for an assumed value of r_2/s. Enter the slip-ampere curve and obtain the value of slip corresponding to the calculated value of I. Obtain r_2 by multiplication of the assumed value of r_2/s by this value of slip.

Maximum or breakdown torque may be calculated from the equivalent circuit using the value of slip:

$$s = \frac{r_2}{\sqrt{r_1^2 + (x_1 + x_2)^2}}$$

Values of reactance corresponding to the current at the maximum torque point must be used in this calculation.

5.4 Losses

5.4.1 Stator I^2R loss

The stator I^2R loss is equal to $1.5I^2R$ where I is the measured or calculated root-mean-square current per terminal, and R is the resistance between any two line terminals. The resistance shall be corrected to a temperature equal to the specified external coolant temperature plus the rated-load temperature rise by resistance. When load tests are made, the winding temperature rise shall be determined by resistance measurement for rated load and may be so determined for other loads.

When load tests are not made, the resistance shall be corrected to a temperature equal to the specified external coolant temperature plus the specified winding temperature rise by resistance.

5.4.2 Rotor I^2R loss

The rotor I^2R loss should be determined from the slip using the following equation:

$$W_2 = (W_{\text{in}} - W_1 - W_{fe})s$$

where

W_2 is rotor I^2R loss
W_{in} is stator power input
W_1 is stator I^2R loss
W_{fe} is iron core and can loss
s slip, per unit

5.4.3 Iron core and can loss, and friction and fluid loss

Iron core and can loss, and friction and fluid loss, should be determined as described in 5.7.

5.4.4 Stray-load loss

The stray-load loss is defined as the total loss in a machine minus the sum of friction and fluid loss, stator I^2R loss, rotor I^2R loss, and no-load iron core and can loss. Stray-load loss should be determined as described in 5.10.

5.5 Slip

When load tests are made, the slip shall be measured directly for the range of load for which the efficiency is determined, whereby slip, s, is defined as

$$s = \frac{n_{\mathrm{syn}} - n_m}{n_{\mathrm{syn}}}$$

where

n_{syn} is synchronous speed
n_m is actual mechanical speed

5.5.1 Measurement of slip

All slip measurements shall be conducted over a minimum period of 30 s or over a period of 10 revolutions of slip, whichever is the longer time. Internal coolant temperature shall be measured during this test.

5.5.2 Correction for temperature

For prototype tests, the average rotor conductor temperature should be monitored. Slip measurements should be made with the internal coolant at the temperature corresponding to rated output of the machine under rated conditions. If this is not possible, slip measurements should be corrected to the temperature corresponding to rated operation as follows:

$$s_r = s_m\left(\frac{K_2 + t_r}{K_2 + t_m}\right)$$

where

s_r is slip corrected to internal coolant temperature t_r
s_m slip measured at internal coolant temperature t_m
t_r internal coolant temperature when the machine is operating continuously at rated load under rated conditions, in °C
t_m is observed internal coolant temperature during the slip test, in °C
K_2 is a constant whose value depends upon the rotor winding; 234.5 for copper and brass; 225 for aluminum based on volume conductivity of 62%

5.6 Power factor

The power factor is the ratio of power input to voltampere input. In calculating performance from an equivalent circuit, power factor is equal to the ratio of the total resistance to the total impedance.

5.7 Tests with no load

The test with no load is made by running the machine at rated voltage and frequency without connected load. The machine shall be operated until the power input does not vary by more than 3% between two successive readings at the same voltage at half-hour intervals.

The magnetic gap should be filled with the fluid for which the machine is designed. The temperature of the fluid should be within 5 °C of the rated value. Specific designs may require substantial pressures to avoid damage to the motor. With incompressible fluids, ambient pressure may generally be varied over a considerable range without significantly affecting losses.

5.7.1 Losses

The reading of input power is the total of the losses in the motor at no load. Subtracting the stator I^2R loss from the input gives the sum of the friction and fluid loss, and the iron core and can loss at no-load speed. The term *can loss*, as used in the test procedure, includes any electromagnetic loss in the magnetic gap fluid due to interaction between the magnetic field and the conductive nature of the gap fluid (i.e., liquid metal).

In interpolating between test points, friction and fluid loss may be assumed to vary exponentially as the 2.8th power of the speed. Several methods to separate friction and fluid loss from iron core and can loss are described in the following subclauses.

5.7.1.1 Variable-voltage method

In this test, voltage, current, power input, and slip are measured at rated frequency and at voltages ranging from 125% of rated voltage down to the point where further voltage reduction increases the current (usually about 25% of rated voltage). A curve of power input minus stator I^2R loss versus voltage is plotted and the curve is extrapolated to zero voltage. The intercept with the zero voltage axis is taken as the friction and fluid loss.

This method leads to a test figure for friction and fluid loss that is less than the friction and fluid loss for the machine at rated speed. This occurs because the speed of the motor varies during the test, approaching the speed corresponding to maximum motor torque at the lowest voltage point. The friction and fluid loss at any slip, s_1, is determined from this value of friction and fluid loss as follows:

$$W_{f1} = \left(\frac{1 - s_1}{1 - s_m}\right)^{2.8} W_{fm}$$

where

W_{f1} is friction and fluid loss at slip, s_1

W_{fm} is friction and fluid loss at slip, s_m

s_1 is slip at which friction and fluid loss is to be calculated, per unit

s_m is highest stable slip at which input measurements are made on no-load test, per unit

5.7.1.2 Duplicate-speed method

In this test, the machine is run without external load with balanced voltages applied at rated frequency. Power input and speed of the motor are measured. The voltage is adjusted to a value such that the motor speed is that corresponding to full load at rated voltage. Power input, W_1, is measured. Friction and fluid loss, W_f, is determined as follows:

$$W_f = \left(\frac{\text{rated power output}}{\text{rated power input} - W_1}\right) W_1$$

This method is based on the assumption that at any constant speed, W_f is constant, and all other losses and the power output vary with voltage (or current) in the same manner. The method may also be used where motor parameters vary with voltage (or current) in any known manner if power output and input are calculated for the values of voltage (or current) present during the test.

5.7.1.3 Retardation method

For this method, the rotational moment of inertia of the rotating parts must be known either by calculation or by measurement. The motor is run at no-load at constant voltage and frequency until the power input does not vary by more than 3% between two successive readings at the same voltage at half-hour intervals. The motor is then disconnected from the line and allowed to decelerate. From the rate of deceleration and the inertia, the friction and fluid loss is calculated by the following formula:

$$W_f = K_3 \cdot J \cdot n \cdot \frac{dn}{dt}$$

where

W_f	is friction and fluid loss, in W, at speed n
J	is polar moment of inertia of rotor assembly
n	is instantaneous speed, rev per min
$\frac{dn}{dt}$	is deceleration corresponding to speed n, r/min, r/min/s
K_3	is 4.62×10^{-4} if J is in lb·ft^2
K_3	is $0.l602 \times 10^{-4}$ if J is in kg·m^2

To obtain accurate results by the use of this method, very accurate measurement of speed and deceleration is required. It may be advisable to take measurements as often as every 0.25 s.

5.7.1.4 Dynamometer method

In this method, the test machine is coupled to a dynamometer and driven at constant speed. No electric power is supplied to the test machine. The corrected dynamometer output is equal to the friction and fluid loss of the test machine at the speed of the test. The dynamometer should be sensitive to 1% of the torque corresponding to friction and fluid loss.

5.8 Tests with load

Tests with load are made for determination of efficiency, power factor, speed, and temperature rise. For all tests with load, the machine should be properly aligned and securely fastened. The usual procedure is to take readings at higher loads first and follow with readings at lower loads.

5.9 Tests with locked rotor

When possible, this test should include a point at rated voltage and frequency because current may not be directly proportional to voltage due to saturation of the leakage flux paths. All readings must be taken quickly to limit machine temperature and the machine temperature should not be allowed to exceed the rated value. For prototype tests, the rotor conductor temperature should be monitored and recorded during locked rotor tests. Methods for doing this include fiber-optic infra-red imaging and the direct thermocouple technique.

5.9.1 Torque

The torque may be measured using a rope and pulley, a brake or beam, or a torsional device. Some motors are subject to significant variations in locked-rotor torque, depending on the angular position of the rotor with respect to the stator. The locked rotor torque is taken as the minimum torque developed at rest in all angular positions of the rotor.

5.9.2 Power

Readings of power input shall be taken simultaneously with those of current and torque.

5.9.3 Impedance

When the motor performance is to be determined by the equivalent circuit method, impedance data are required. These consist of a series of readings of voltage, current, and power taken at different values of current with the rotor blocked.

Simultaneous readings of voltage and current in all phases and of power input shall be taken at several points, establishing the values with special care in the neighborhood of full-load current. The stator winding temperature or resistance shall also be recorded at each point. Taking the higher readings first will help to equalize the temperature. Form 5 may be used for calculating motor circuit parameters from impedance test data.

The reactance shall be measured at rated load current at approximately 25% of rated frequency. The reactance is determined by multiplying the reactance measured at the test frequency by the ratio of rated frequency to test frequency.

If rotor resistance is to be determined from impedance test data, the test should be made at a frequency no greater than 25% of rated frequency.

Impedance data shall be plotted, showing current and power input as functions of voltage.

5.10 Tests for stray-load loss

Stray-load loss is determined from mechanical output measurement performance tests or by the segregated-loss method described in 5.10.2.

5.10.1 Mechanical-output method

When mechanical output is measured, stray-load loss is taken as the losses unaccounted for by friction and fluid loss, stator I^2R loss, rotor I^2R loss, and no-load iron core and can loss.

$$W_{LL} = W_{\text{in}} - W_{\text{out}} - (W_f + W_1 + W_2 + W_{fe})$$

where

W_{LL} is stray-load loss
W_{in} is power input
W_{out} is power output
W_f is friction and fluid loss
W_1 is stator I^2R loss
W_2 is rotor I^2R loss
W_{fe} is iron core and can loss

5.10.2 Segregated-loss method

When mechanical output is not measured, stray-load loss is regarded as consisting of two components.

5.10.2.1 Fundamental frequency stray-load loss

The first component occurs at fundamental frequency and is due to stator leakage flux. It consists of eddy current and hysteresis losses in stator conductors, stator punchings, and structural parts. With the rotor removed from the stator, balanced voltages at rated frequency are applied to the stator terminals and a series of simultaneous readings of voltage, current, and power in all phases is taken. The stator winding temperature or resistance is recorded at each point. If the stator is “canned,” precautions must be taken to prevent excessive temperature rise of the can. This portion, LL_s, of stray-load loss is equal to the power input less stator I^2R loss and less stator iron core and can loss. The stator iron core and can loss during this test may be calculated from the data taken during this test and the value of iron core and can loss for rated conditions. Form 5 may be used for this calculation.

5.10.2.2 Higher frequency stray-load loss

The stray-load loss occurring at high frequencies may be determined by a reverse-rotation test. With the motor completely assembled, balanced polyphase voltages of rated frequency are supplied to the stator winding terminals. The rotor is driven by external means at exactly synchronous speed in the direction opposite to the stator field rotation. The mechanical power required to drive the rotor is measured both with and without voltage applied to the stator. The voltage, current, and power supplied to the stator are measured. At least six test points approximately equally spaced from one-quarter (0.25) to one and one-half (1.5) times rated current shall be taken. The stator winding temperature or resistance shall be taken at each load point. This portion of stray-load loss, LL_r, is equal to the mechanical power input to the rotor less the electric power input to the stator less the I^2R loss in the stator winding, the fundamental stray-load loss, and the iron core and can loss for the conditions of the test. The appropriate value of iron core and can loss may be calculated from the equivalent circuit. Form 5 may be used for this calculation. LL_r shall be plotted as a function of current I_2.

5.10.2.3 Total stray-load loss

Stray-load loss is the sum of LL_s and LL_r. For a particular value of stator current, I, and no load stator current, I_0, the value of LL_s and LL_r shall be taken corresponding to I_2, where

$$I_2 = \sqrt{I^2 - I_0^2}$$

5.11 Tests for speed–torque and speed–current

5.11.1 General

5.11.1.1 Speed–torque characteristics

The speed–torque characteristic is the relation between torque and speed, embracing the range from zero to synchronous speed. Winding and coolant temperatures shall not be in excess of rated values at any time when test data are taken.

5.11.1.2 Speed–current characteristics

The speed–current characteristic is the relation between current and speed.

5.11.2 Method

The speed–torque and speed–current tests may be made with a dynamometer or a brake as the load. Measurements of current, voltage, and speed shall be made. The torque output is obtained from the dynamometer or brake readings plus the appropriate correction for dynamometer or brake windage loss.

The speed–torque and speed–current tests shall be made at rated voltage or as near to it as is practical. When it is necessary to make these tests at reduced voltage, current and torque for rated voltage are calculated from the reduced voltage data by the following relationships:

$$I_r = \left(\frac{V_r}{V_t}\right) I_t;$$

$$T_r = \left(\frac{V_r}{V_t}\right)^2 T_t$$

where

I_r and I_t indicate values of current corresponding to rated and test voltages, respectively;
T_r and T_t indicate values of torque corresponding to rated and test voltages, respectively;
V_r and V_t indicate rated and test values of voltages, respectively.

Due to saturation, actual values of current and torque corresponding to full voltage will always be somewhat greater than indicated by the relationship above.

This test shall be conducted at values of speed such that starting torque, minimum torque, and maximum torque are determined; also, maximum and minimum of local torque irregularities due to harmonics shall be determined when they are present in significant degree.

6. Temperature test

6.1 Purpose

Temperature tests are made to determine the temperature rise of various parts of the machine above the specified coolant temperature under specified loading conditions.

6.2 General

The temperature and flow of the supplied coolant should be maintained at approximately rated conditions during temperature tests.

6.2.1 Temperature measuring devices

Temperature measuring devices shall be in accordance with IEEE Std 119-1974. At the start of the temperature test, all instruments shall be checked to make certain that there are no appreciable instrument errors due to stray-field effects.

6.3 Methods of temperature measurements

The commonly used methods for determining temperature are listed below.

a) Change of electrical resistance.
b) Direct measurement. The instruments employed are as follows:
    1) Liquid-in-glass thermometers
    2) Thermocouples
    3) Resistance temperature detectors

6.3.1 Change of electrical resistance

The average temperature of a machine winding is determined by comparing the resistance of the winding at the temperature to be determined with the resistance at a known temperature. The following formula applies:

$$t_1 = \frac{r_1}{r_c}(K_2 + t_c) - K_2$$

where

t_1 is average temperature of winding, corresponding to r_1, in °C
r_1 is winding resistance at temperature t_1, in Ω
t_c average temperature of winding, corresponding to resistance r_c, in °C
r_c is winding resistance at temperature t_c, in Ω
K_2 is a constant: 234.5 for copper; 225 for aluminum

In a squirrel-cage machine, the change in rotor resistance due to heating results in a change in slip for a constant load condition. For a given value of torque, the temperature of the rotor can be indirectly determined from the hot and cold slip readings by substituting s_1 for r_1 and s_c for r_c in the formula of 6.3.1. The slip shall be accurately determined for both hot and cold conditions. Small errors in the slip values lead to considerable errors in the calculated temperature.

6.3.2 Direct temperture measurement

The following direct temperature readings may be useful and shall be measured as indicated.

6.3.2.1 Maximum winding surface temperature

The maximum winding surface temperature shall be measured in accordance with IEEE Std 112-1991, except that the thermocouple is the preferred instrument and that the temperature-detecting devices shall be located in the anticipated maximum temperature areas of the motor winding.

6.3.2.2 Internal coolant

It is customary and desirable to measure the temperature of the internal coolant. Readings may be taken adjacent to bearings to provide an indication of change in bearing condition or the degree of isolation of the magnetic gap region from other areas.

6.3.2.3 Wells

Because of mechanical design and for maintenance of machine integrity, direct contact of the temperature-measuring device and the part whose temperature is being measured may be impractical.

In such cases, wells may be installed, providing a path from the exterior of the machine to a point adjacent to the part whose temperature is being measured. Various types of direct temperature-measuring devices may be inserted in the wells. The thermal isolation occasioned by the well makes it desirable to calibrate such an arrangement by a more direct measurement.

6.4 Measurement of ambient and external coolant temperatures

The recommendations of IEEE Std 119-1974 shall be followed in the measurement of ambient and external temperatures.

6.5 Procedure

The machine may be loaded by one of the methods outlined under performance determination. The test shall be made at rated voltage and frequency. The loading may be determined by direct measurement of output or input. A machine having more than one rating shall be tested at the rating that produces the greatest temperature rise. In cases where this cannot be predetermined, the machine shall be tested separately at each rating.

6.5.1 Test duration

The test shall be continued for the specified time (for machines not continuously rated), or until constant temperatures have been reached.

On continuously rated machines, when a long time is required to attain steady temperature, reasonable (25–50%) overloads during the preliminary heating periods are permissible in order to shorten the time of test.

CAUTION

Temperature limitations should not be exceeded.

6.5.2 Data recording intervals

For continuously rated machines, readings shall be taken at intervals not exceeding one-half hour. For continuously rated machines, the temperature test shall continue until there is a 1°C or less change in temperature rise between two sucessive readings. For noncontinuously rated machines, readings shall be taken at intervals consistent with the time rating.

The meaningful measurement of temperatures after shutdown requires quick stopping of the machine at the end of the temperature test. Temperatures after shutdown shall be measured as frequently as possible until temperature readings have begun a decided decline from their maximum values. It is recommended that these temperature readings be taken at least every two seconds.

6.5.3 Resistance measurements

Resistance measurements shall be made at outlined in IEEE Std 118-1978. Care shall be taken to secure accurate resistance measurements, since a small error in measuring resistance will cause a comparatively large error in determining the temperature. Resistance measurements shall be made as soon as possible after the rotor stops. Coolant flow should be maintained while shutdown readings are made. The measurements shall be made at frequent intervals thereafter until a period of 3 min or 4 min has elapsed from the time the machine was de-energized. A curve shall be plotted of resistance versus time and the curve shall be extrapolated back to zero time to determine the resistance at the time of de-energization. The average winding temperature shall then be determined using the method of 6.3.1.

6.6 Temperature rise

When the machine is cooled by the internal coolant, the temperature rise is the observed machine temperature minus the internal coolant inlet temperature. When the machine is cooled by an external coolant, the temperature rise is the observed temperature minus the external coolant inlet temperature.

7. Miscellaneous tests

7.1 Insulation resistance

Insulation resistance tests shall be made in accordance with IEEE Std 43-1974. This test is normally made at room temperature. The test voltage shall be successively applied between each electric circuit and the frame with the windings not under test and the other metal parts connected to the frame.

7.2 Dielectric tests

Dielectric tests shall be conducted in accordance with IEEE Std 4-1995.

7.3 Resistance measurements

For the procedures recommended in the measurement of resistance, refer to IEEE Std 118-1978.

7.4 Noise

For the procedures recommended in the measurement of noise, refer to IEEE Std 85-1973.

7.5 Vibration

Vibration measurements shall be made in each of three mutually perpendicular axes, with one axis being parallel to the motor shaft. Measurements in the axes perpendicular to the shaft shall be made at both ends of the machine, at points adjacent to the bearings. The maximum double amplitude measured in this manner is taken as the measure of the vibration. Mounting conditions will affect the vibration of a machine.

Annex

(normative)

Forms

Form 1—Report of routine tests

Date of test

Manufacturer
Address of manufacturer
Purchaser
Address of purchaser
Manufacturer’s order number
Purchaser’s order number

Nameplate data

Power hp	**Speed r/min**	**Phase**	**Frequency Hz**	**Line voltage**	**Current A**	**Type**	**Serial number**	**Temp. (rise) °C**	**Time rating**	**Design letter**	**Locked rotor kVA/hp code**

Test data

Serial no.	**No load**					**Locked rotor**				**Winding res. between terminals**		**Insulation res. 1 min**		**Dielectric test kV**
	Frequency Hz	**Line voltage**	**Current A**	**Power kW**	**Speed r/min**	**Frequency Hz**	**Line voltage**	**Current A**	**Power kW**	**Ω**	**Temp. °C**	**MΩ**	**V**	

Approved by
Date

Form 2—Report of complete tests (supplement to Form 1)

Date of test ____________________

Manufacturer ____________________
Address of manufacturer ____________________
Purchaser ____________________
Address of purchaser ____________________
Manufacturer’s order number ____________________
Purchaser’s order number ____________________

Nameplate data

Power hp	Speed r/min	Phase	Frequency Hz	Line voltage	Current A	Type	Serial number	Temp. (rise) °C	Time rating	Design letter	Locked rotor kVA/hp code

Performance data

Winding resistance, terminal to terminal, Ω ________ at ________ °C At locked rotor, ______ %Voltage
*Breakdown torque, ________________ *Torque, ________________
Current, A ________________

Test method ____________________________ Winding temp, by ________________
(Resistance, thermocouples, etc.)

Time of test h	Line voltage	Current A	Power input kW	Power output hp	Speed r/min	Slip percent	Efficiency percent	Power factor percent	Supplied coolant				Internal coolant		Winding temp. °C
									Inlet temp. °C	Outlet temp. °C	Inlet press. †	Flow ††	Temp. °C	Press. †	

*Specify units as lb·ft or N·m.
†Specify units as psi or pascal.
††Specify units as gpm or m^3/s.

Approved by ________________
Date ________________

Form 3—Report of mechanical-output measurement test

Power ____________ hp
Line voltage ____________ V
Frequency ____________ Hz
Synch. speed ____________ r/min
Phase ____________

Date of test ____________
Serial no. ____________
Time rating ____________
Temperature (rise) ____________ °C

Line	Test point	1	2	3	4	5	6	7	8
1	Stator winding temperature, °C								
2	Ambient temperature, °C								
3	Supplied coolant								
4	Inlet temperature, °C								
5	Inlet pressure, *								
6	Flow,†								
7	Internal coolant								
8	Temperature, °C								
9	Pressure,*								
10	Observed slip								
11	Corrected slip								
12	Speed, r/min								
13	Observed torque,††								
14	Corrected torque,††								
15	Power output, hp								
16	Line current, A								
17	Power factor, percent								
18	Observed power input, kW								
19	Corrected power input, kW								
20	Efficiency, percent								

NOTES

Line 11. See 5.5.
Line 14. See 5.3.2.
Line 19. Line 18 plus additional winding loss due to winding temperature increase equal to rated minus actual temperature of supplied coolant.
Line 20. Line 15 multiplied by 74.6 divided by Line 19.

Performance curve no. ____________

Data from performance curve

Load, percent rated	0	25	50	75	100	125	150
Power factor, percent							
Efficiency, percent							
Speed, r/min							
Line current, A							

Approved by ____________
Date ____________

* Specify units as psi or pascal.
† Specify units as gpm or m^3/s.
†† Specify units as lb·ft or N·m.

Form 4—Report of segregated loss performance data

Power ____________________ hp

Line voltage _______________ V

Frequency _________________ Hz

Synch. speed ______________ r/min

Phase ____________________

Date of test ____________________

Serial no. ______________________

Time rating ____________________

Temperature (rise) _____________ °C

Line	Test point	1	2	3	4	5	6	7	8
1	Stator winding temperature, °C								
2	Ambient temperature, °C								
3	Supplied coolant								
4	Inlet temperature, °C								
5	Inlet pressure, *								
6	Flow,†								
7	Internal coolant								
8	Temperature, °C								
9	Pressure,*								
10	Observed slip								
11	Corrected slip								
12	Speed, r/min								
13	Line current, A								
14	Power factor, percent								
15	Observed power input, kW								
16	Corrected power input, kW								
17	Stator I^2R loss, kW								
18	Friction and fluid and core and can loss, kW								
19	Input to rotor, kW								
20	Rotor I^2R loss, kW								
21	Stray-load loss, kW								
22	Total loss, kW								
23	Power output, hp								
24	Efficiency, percent								

Form 4—Report of segregated loss performance data *(continued)*

NOTES

Line 11. See 5.5.
Line 16. Line 15 plus additional winding loss due to winding temperature increase equal to rated minus actual temperature of supplied coolant.
Line 17. Based on actual winding temperature plus rated minus actual temperature of supplied coolant.
Line 19. Line 16–(line 17 + core and can loss).
Line 20. Line 19 multiplied by line 11.
Line 22. Line 17+ line 18 = line 20 +line 21.
Line 23. [(Line 16)–(line 22)] divided by 0.746.
Line 24. Line 23 multiplied by 74.6 divided by line 16.
*Specify units as psi or pascal.
†Specify units as gpm or m^3/s.

Data from performance curve

Load, percent rated	0	25	50	75	100	125	150
Power factor, percent							
Efficiency, percent							
Speed, r/min							
Line current, A							

Approved by ____________________
Date ____________________

Form 5—Equivalent circuit nomenclature and formulas for calculation motor parameters

All impedances, admittances, and voltages are per phase for an equivalent three-phase Y-connected motor. Powers and voltamperes are per complete motor.

Nomenclature

b_M	Magnetizing susceptance, siemens	VAR	Reactive voltamperes, vars
V	Phase voltage, V	W	Power, W
f	Frequency, Hz	W_1	Stator I^2R loss, W
g_{fe}	Core and can conductance, siemens	W_2	Rotor I^2R loss, W
I	Stator line current, A	W_{fe}	Core and can loss, W
I_2	Rotor current, A	W_f	Friction and fluid loss, W
LL_s	Stator stray-load loss, W	W_{LL}	$LL_s + LL_r$ Stray-load loss, W
LL_r	Rotor stray-load loss, W	P_r	Mechanical input during test for LL_r
		W_s	Electric input during test for LL_s
n	Speed, r/min	W_r	Electric input during test for LL_r
n_m	Actual mechanical speed, r/min	x_1	Stator leakage reactance, Ω
n_{syn}	Synchronous speed, r/min	x_2	Rotor leakage reactance, Ω (referred to stator)
r_1	Stator resistance, Ω	x_M	Magnetizing reactance, Ω
r_2	Rotor resistance, Ω (referred to stator)		
s	Slip, fraction of synchronous speed		

Subscripts

L	Quantities pertaining to impedance test
s	Quantities pertaining to test for determination of LL_s
r	Quantities pertaining to test for determination of LL_r
o	Quantities pertaining to no-load test or operation

Procedure

A relationship between x_1 and x_2 must be assumed. When design details are available, use the calculated ratio,

$$\left(\frac{x_1}{x_2}\right);\text{otherwise use }\left(\frac{x_1}{x_2}\right) = 1.0$$

$$VAR = \sqrt{(3VI)^2 - W^2}$$

$$x_M = \frac{3V_o^2}{VAR_o - 3I_o^2 x_1}\left(\frac{1}{1 + \frac{x_1}{x_M}}\right)^2 \qquad (1)$$

$$x_{1L} = \frac{VAR_L}{3I_L^2\left(1 + \frac{x_1}{x_2} + \frac{x_1}{x_M}\right)}\left(\frac{x_1}{x_2} + \frac{x_1}{x_M}\right) \qquad (2)$$

Form 5—Equivalent circuit nomenclature and formulas for calculation motor parameters *(continued)*

$$x_1 = \frac{f}{f_L} x_{1L} \tag{3}$$

$$x2 = \frac{x_2}{\left(\frac{x_1}{x_2}\right)} \tag{4}$$

Equations (1) and (2) may be solved as follows:

1. Solve equation (1) for x_M, assuming $x_1 = 0$;

2. Solve equation (2) for x_{1L}, using $x_1 = 0$ from step 1;

3. Solve equation (1) for x_M, using x_1 from equation (3);

4. Continue iteration solution until stable values of x_1 and x_M are obtained within 0.1%.

$$r_1 = \frac{1}{2}[\text{resistance between any two terminals}] \tag{5}$$

$$W_{feo} = W_o - W_{fo} - 3I_o^2 r_1$$

Determine W_{fo} per 5.7.

$$g_{fe} = \frac{W_{feo}}{3V_o^2}\left(1 + \frac{x_1}{x_M}\right)^2 \tag{6}$$

$$r_2 = \left(\frac{W_L}{3I_L^2} - r_1\right)\left(1 + \frac{x_2}{x_1}\frac{x_1}{x_M}\right)^2 - \left(\frac{x_2}{x1}\right)^2 x_{1L}^2 g_{fe} \tag{7}$$

$$LL_s = W_s - 3I_s^2 r_1 - 3(V_s - I_s x_1)^2 g_{fe} \tag{8}$$

$$LL_r = P_r - W_f - [W_r - 3I_r^2 r_1 - LL_s - 3(V_r - I_r x_1)^2 g_{fe}] \tag{9}$$

LL_s in equation (9) corresponds to I_r (5.10.2.3).

Approved by______________________
Date ______________________

Form 6—Summary of motor characteristics segregated-loss methods

Power ____________________ hp
Line voltage ________________ V
Frequency _________________ Hz
Synch. speed _______________ r/min
Phases ___________________

Motor serial no. ________________
Date of test ____________________
Time rating ____________________
Temperature (rise) _____________ °C

Summary of tests

	No load	Impedance data at _____Hz	Stray-load loss	
			Fund. freq., W	**High freq., W**
Line voltage, V	$\sqrt{3}V_o$	$\sqrt{3}V_L$	$\sqrt{3}V_s$	$\sqrt{3}V_r$
Line current, A	I_o	I_L	I_s	I_r
Power, electric, W	W_o	W_L	W_s	W_r
Power, mechanical, W				P_r

Constants

V ________________ V/phase
r_1 ________________ Ω at __________ °C
r_2 ________________ Ω at __________ °C
g_{fe} ________________ S (siemens)
b_M ________________ S (siemens)

x_1 ________________ Ω
x_2 ________________ Ω
W_f ________________ W
W_{fe} ________________ W
W_{LL} ________________ W
} **at rated conditions**

Summary of characteristics

Load, percent rated	0	25	50	75	100	125	150
Speed, r/min							
Line current, A							
Efficiency, percent							
Power factor, percent							

Approved by ________________________
Date ________________________

Form 7—Solution of equivalent circuit

Motor serial no. ____________ Type ________ Horsepower ________

Voltage ________ Synchronous speed ________ Frequency ________ Phases ________

Line no.	Description	Load points							
		1	2	3	4	5	6	7	8
1	s								
2	$r_2/_s + jx_2 = z_2$								
3	$g_2 - jb_2 = y_2 = \frac{1}{z_2}$								
4	$g_{fe} - jb_M$								
5	$G_{M2} - jB_{M2} = Y_{M2}$								
6	$R_{M2} + jX_{M2} = Z_{M2} = \frac{1}{Y_{M2}}$								
7	$r_1 + jx_1$								
8	$R + jX + Z$								
9	Percent power factor = $R/Z \times 100$								
10	$I = V/Z$								
11	$I_2 = I\,(Z_{M2}/z_2)$								
12	Input = $3I^2R \times 10^{-3}$								
13	Stator I^2R Loss = $3I^2r_1 \times 10^{-3}$								
14	Can and core loss = $3I^2\,Z^2{}_{M2}\,g_{fe} \times 10^{-3}$								
15	Rotor input = (line 12) – (line 13) – (line14)								
16	Rotor I^2R loss = (line 1) × (line 15)								
17	W_f								
18	W_{LL}								
19	Total losses								
20	Percent efficiency								
21	Output horsepower								
22	Speed (r/min)								
23	Torque (lb·ft)								

Form 7—Solution of equivalent circuit *(continued)*

NOTES

Line 5. $G_{M2} = g_2 + g_{fe}; B_{M2} = b_2 + b_M$

Line 8. $R = R_{M2} + r_1; X = X_{M2} + x_1$

Line 17. See 5.7.

Line 18. See 5.10.

Line 19. Sum of lines 13, 14, 16, 17, and 18.

Line 20. Percent efficiency = $\left(1 - \frac{\text{Line 19}}{\text{Line 12}}\right) \times 100\%$

Line 21. Output horsepower = $\frac{\text{Line 12} - \text{Line 19}}{0.746}$

Line 22. Speed (r/min) = $[1 - (\text{Line 1})] \times \text{synchronous r/min}$

Line 23. $\frac{\text{Line 21}}{\text{Line 22}} \times 5250$

Approved by ____________________________

Date ____________________________