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

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THE INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGINEERS, Inc.

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

Sponsor

Rotating Machinery Committee of the
IEEE Power Engineering Society

Foreword

(This foreword is not a part of IEEE Std 252-1977, 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 112A-1964) (ASA C50.20-1954), American Standard Test Code 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.

This Test Procedure was written by a Working Group of the Induction Machinery Subcommittee of the Rotating Machinery Committee. The Working Group was composed of:

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Contents

IEEE 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.

2. General

2.1 Kinds of Tests. These motors are normally given either a routine test or a complete test

2.1.1 *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.

2.1.2 *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 which are described in this Test Procedure, and other tests, such as measurement of shaft currents which are not covered in this Test Procedure, may be used.

2.2 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. Electrical Measurements

3.1 General. Electrical measurements shall be made in accordance with the IEEE Std 120-1955, Master Test Code for Electrical Measurements in Power Circuits.

3.2 Power Supply. The supply voltage shall closely approach sine-wave form and shall provide balanced phase voltages. The frequency shall be closely regulated and shall be measured within an accuracy of 0.1 percent of rated value.

3.3 Instrument Selection. The instruments used in electrical measurements shall be selected to give indications well up on the scale, ie, where a fraction of a division is easily estimated and where such a fraction is a small percentage of the value read.

3.4 Instrument Transformers. When current and potential 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.

3.5 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.

3.6 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.

3.7 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.

4. Performance Determination[1]

4.1 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.

4.2 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.

4.3 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.

4.3.1 *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 to one and one-half times rated load.

4.3.2 *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:

$$W = K \cdot n \cdot T$$

where
W = output power, watts
T = torque
K = 0.142 if T is in lb • ft
K = 0.1047 if T is in N•m.
n = speed, revolutions per minute (r/min)

Torque corrections appropriate to the equipment used shall be made.

4.3.2.1 *Brake.* The "tare," if present, shall be determined and compensated.

4.3.2.2 *Dynamometer.* The dynamometer rating should not exceed three times the machine rating, and it should be sensitive to a torque of 0.25 percent of the rated torque.

4.3.3 *Segregated-Loss Methods.* The input shall be measured as indicated in Section 4.3.3.1 or calculated as described in Section 4.3.3.2. 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 following losses:

Loss Designation	Description
(1) Friction and fluid loss	Mechanical loss due to rotation of rotor assembly in its normal environment
(2) Core loss	Loss in iron at no load
(3) Can loss	Loss in cans at no load
(4) Stator I^2R loss	Loss in stator windings
(5) Rotor I^2R loss	Loss in rotor windings
(6) Stray-load loss	Load dependent loss in iron, rotor and stator cans, and eddy current and high-frequency losses in conductors

4.3.3.1 *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:

(1) stator resistance
(2) no-load current and no-load losses
(3) rotor slip
(4) maximum stator winding surface temperature or stator resistance.
(5) watts input
(6) line current
(7) stray-load loss.

[1]See Form 5 for Nomenclature.

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

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

4.3.3.2 *Equivalent-Circuit Calculations.* When tests under load cannot be made, operating characteristics may be calculated from the equivalent circuit (See Fig 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 work sheet upon which the curcuit calculations may be made.

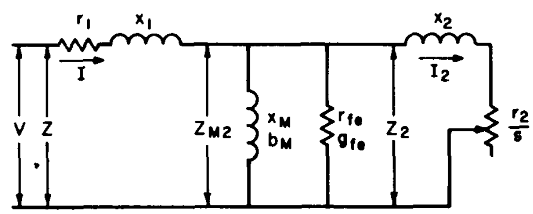

Fig 1
Equivalent Circuit

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

4.3.3.2.2 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 Section 4.9.3). An alternate method of obtaining r_2 is described in Section 4.3.3.2.4.

4.3.3.2.3 Form 5 is arranged on the basis of x_1 and x_2 remaining constant throughout the range of operation of 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.

4.3.3.2.4 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.

4.3.3.2.5 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.

4.4 Losses.

4.4.1 *Stator I^2 R 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.

4.4.2 *Rotor I^2 R 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 rotor I^2R loss
W_{in} stator power input
W_1 stator I^2R loss
W_{fe} core and can loss
s slip, per unit.

4.4.3 *Core and Can Loss, and Friction and Fluid Loss.* Core and can loss, and friction and fluid loss should be determined as described in Section 4.7.

4.4.4 *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 core and can loss. Stray-load loss should be determined as described in Section 4.10.

4.5 Slip. When load tests are made, the slip shall be measured directly for the range of load for which the efficiency is determined.

4.5.1 *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.

4.5.2 *Correction for Temperature.* 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:

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

where

s_r slip corrected to internal coolant temperature t_r

s_m slip measured at internal coolant temperature t_m

t_r internal coolant temperature, in degrees Celsius, when the machine is operating continuously at rated load under rated conditions

t_m observed internal coolant temperature, in degrees Celsius, during the Slip Test

K a constant whose value depends upon the rotor winding; 234.5 for copper and brass; 255 for aluminum based on a volume conductivity of 62 percent.

4.6 Power Factor The power factor is the ratio of power input to volt—ampere input. In calculating performance from an equivalent circuit, power factor is equal to the ratio of the total resistance to the total impedance.

4.7 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 becomes constant.

The magnetic gap should be filled with the fluid for which the machine is designed. The temperature of the fluid should be approximately 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.

4.7.1 *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 core and can loss at no-load speed. The term can loss, as used in this 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 (ie, liquid metal).

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

4.7.1.1 *Variable-Voltage Method.* In this test, voltage, current, power input, and slip are measured at rated frequency and at voltages ranging from 125 percent of rated voltage down to the point where further voltage reduction increases the current (usually about 25 percent 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 which 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:

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

Where

W_{fl} friction and fluid loss at slip, s_1

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

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

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

4.7.1.2 *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.

4.7.1.3 *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 is constant. 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:

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

where

W_f friction and fluid loss, watts, at speed n

J polar moment of inertia of rotor assembly

n instantaneous speed, revolutions per minute

$\frac{dn}{dt}$ deceleration corresponding to speed n revolutions per minute per second

K = $4.6.2 \times 10^{-4}$ if J is in lb · ft²

K = 0.1602×10^{-4} if J is in kg · m².

To obtain accurate results by the use of this method, very accurate measurement of speed and deceleration is required.

4.7.1.4 *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 percent of the torque corresponding to friction and fluid loss.

4.8 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.

4.9 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.

4.9.1 *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.

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

4.9.3 *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 reisistance 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.

4.9.3.1 The reactance shall be measured at rated load current at approximately 25 percent 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.

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

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

4.10 Tests for Stray-Load Loss. Stray-load loss is determined from mechanical output measurement performance tests or by the Segregated-

Loss Method described in Section 4.10.2, below.

4.10.1 *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 core and can loss.

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

where

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

4.10.2 *Segregated-Loss Method.* When mechanical output is not measured, stray-load loss is regarded as consisting of two components.

4.10.2.1 The first 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 core and can loss. The stator core and can loss during this test may be calculated from the data taken during this test plus the value of core and can loss for rated conditions. Form 5 may be used for this calculation.

4.10.2.2 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 to one and one-half 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 core and can loss for the conditions of the test. The appropriate value of 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.

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

$$I_2 = \sqrt{I^2 - I^2_0}.$$

4.11 Tests for Speed—Torque and Speed—Current.

4.11.1 *General.*

4.11.1.1 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.

4.11.1.2 The speed—current characteristic is the relation between current and speed.

4.11.2 *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.

4.11.2.1 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.

5. Temperature Test

5.1 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.

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

5.2.1 Temperature measuring devices shall be in accordance with IEEE Std 119-1974, Master Test Code for Temperature Measurements of Electric Apparatus. At the start of the temperature test, all instruments shall be checked to make certain that there are no appreciable instrument errors or stray-field effects.

5.3 Methods of Temperature Measurements. The commonly used methods for determining temperature are listed below.

(1) Change of Electrical Resistance.

(2) Direct Measurement. The instruments employed are:

(a) liquid-in-glass thermometers,

(b) thermocouples,

(c) resistance temperature detectors.

5.3.1 *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:

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

where

t_1 average temperature of winding, in degrees Celsius, corresponding to r_1

r_1 winding resistance, ohms, at temperature t_1

t_c average temperature of winding, in degrees Celsius, corresponding to resistance r_c

r_c winding resistance, ohms, at temperature t_c

K a constant: 234.5 for copper; 255 for aluminum.

5.3.1.1 In a squirrel-cage machine, the change in rotor resistance due to heating results in a change in slip. 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 Section 5.3.1. 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.

5.3.2 *Direct Temperature Measurement.* The following direct temperature readings may be useful and shall be measured as indicated.

5.3.2.1 *Maximum Winding Surface Temperature.* The maximum winding surface temperature shall be measured in accordance with the American Standard for Alternating-Current Induction Motors, Induction Machines in General and IEEE Std 112A-1964, Test Procedure for Polyphase Induction Motors, 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.

5.3.2.2 *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.

5.3.2.3 *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.

5.4 Measurement of Ambient and External Coolant Temperatures. The recommendations of the IEEE Std 119-1974, Master Test Code for Temperature Measurement of Electric Apparatus, shall be followed in the measurement of ambient and external coolant temperatures.

5.5 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 which produces the greatest temperature rise. In cases where this cannot be predetermined, the machine shall be tested separately at each rating.

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

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

5.5.3 For continuously rated machines, readings shall be taken at intervals not exceeding one-half hour. For noncontinuously rated machines, readings shall be taken at intervals consistent with the time rating.

5.5.4 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.

5.5.5 Resistance measurements shall be made as outlined in IEEE Std 118-1949, Master Test Code for Resistance Measurement. 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 rotating. Coolant flow should be maintained while shutdown readings are made. The measurements shall be made at frequent intervals thereafter until a period of 3 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 Section 5.3.1.

5.6 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.

6. Miscellaneous Tests

6.1 Insulation Resistance. Insulation resistance tests shall be made in accordance with IEEE Std 43-1974, Recommended Practice for Testing Insulation Resistance of Rotating Machinery. 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.

6.2 Dielectric Tests.

6.2.1 Dielectric tests shall be conducted in accordance with the American Standard for Alternating-Current Induction Motors, Induction Machines in General, and IEEE Std 4-1969 (ANSI C68.1-1968), Techniques for Dielectric Tests.

6.3 Resistance Measurements. For the procedures recommended in the measurement of resistance, refer to IEEE Std 118-1949, Master Test Code for Resistance Measurement.

6.4 Noise. For the procedures recommended in the measurement of noise, refer to IEEE Std

85-1973, Test Procedure for Airborne Sound Measurements on Rotating Electric Machinery.

6.5 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.

Form 1
Report of Routine Tests

Date of Test____________________

Manufacturer____________________

Address of Manufacturer____________________

Purchaser____________________

Address of Purchaser____________________

Manufacturer's Order No____________________

Purchaser's Order No____________________

Nameplate Data

Power hp	Speed r/min	Phase	Frequency Hz	Line Voltage	Current A	Type	Serial No	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
	Frequency Hz	Line Voltage	Current A	Power kW	Speed r/min	Frequency Hz	Line Voltage	Current A	Power kW	Ω	Temp °C	MΩ	V	kV

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 No________________
Purchaser's Order No________________

Nameplate Data

Power hp	Speed r/min	Phase	Frequency Hz	Line Voltage	Current A	Type	Serial No	Temp. (Rise) °C	Time Ratime	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____________
Temp. (Rise)____________°C

Line	Test Point	1	2	3	4	5	6	7	8
1	Stator winding temp., °C								
2	Ambient temp., °C								
3	Supplied Coolant								
4	Inlet temp., °C								
5	Inlet press.,*								
6	Flow, †								
7	Internal Coolant								
8	Temperature, °C								
9	Pressure,*								
10	Observed Slip, r/min								
11	Corrected Slip, r/min								
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:

NOTES:

Line 11. See Section 4.5.

Line 14. See Section 4.3.2.

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____________

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

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 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______________
Temp. (Rise)______________°C

Line	Test Point	1	2	3	4	5	6	7	8
1	Stator winding temp., °C								
2	Ambient temp., °C								
3	Supplied Coolant								
4	Inlet temp., °C								
5	Inlet press.,*								
6	Flow, †								
7	Internal Coolant								
8	Temperature, °C								
9	Pressure, *								
10	Observed Slip, r/min								
11	Corrected Slip, r/min								
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	Efficienty, percent								

NOTES:

Line 11. See Section 4.5.
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 volt—amperes are per complete motor.

Nomenclature

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

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,

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

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

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

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

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

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

1. Solve Eq (1) for x_M, assuming $x_1 = 0$;
2. Solve Eq (2) for x_{1L}, using $x_M = 0$ from step 1;
3. Solve Eq (1) for x_M, using x_1 from Step 2;
4. Continue iteration solution until stable values of x_1 and x_M are obtained.

$$r_1 = \frac{1}{2}\,[\text{resistance between any two terminals}] \qquad (3)$$

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

Determine W_{fo} per Section 4.7.

$$g_{fe} = \frac{W_{feo}}{3V_o^2}\left(1 + \frac{x_1}{x_M}\right)^2 \qquad (4)$$

$$r_2 = \left(\frac{W_L}{3I^2_L} - r_1\right)\left(1 + \frac{x_2}{x_1}\ \frac{x_1}{x_M}\right)^2 - \left(\frac{x_2}{x_1}\right)^2 x_{1L}^2 g_{fe} \qquad (5)$$

$$LL_s = W_s - 3I_s^2\, r_1 - 3(V_s - I_s x_1)^2\, g_{fe} \qquad (6)$$

$$LL_r = P_r - W_f - [W_r - 3I_r^2 r_1 - W_s - 3\,(V_r - I_r\, x_1)^2\, g_{fe}\,] \qquad (7)$$

W_s in Eq (7) corresponds to I_r (Section 4.10.2.3).

Approved by ______________________________

Date ______________________________

Form 6
Summary of Motor Characteristics
Segregated-Loss Methods

Motor Serial No.____________

Power____________hp

Date of Test____________

Line Voltage____________V

Frequency____________Hz

Synch. Speed____________r/min

Time Rating____________

Phases____________

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) — (Line 14)								
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)								

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 Section 4.7

Line 18. See Section 4.10.

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

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

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

Line 22. Speed (r/min) = [1 — (Line 1)] × synchronous r/min

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

Approved by ______________________________

Date ______________________________