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IEEE Standard Test Procedure for Polyphase Induction Motors and Generators

IEEE Power Engineering Society

Sponsored by the
Electric Machinery Committee

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Abstract: Instructions for conducting and reporting the more generally applicable and acceptable tests of polyphase induction motors and generators are covered.

Keywords: acceptance and performance testing, generators, induction, machines, motors, polyphase

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Introduction

This introduction is not part of IEEE Std 112-2004, IEEE Standard Test Procedure for Polyphase Induction Motors and Generators.

This standard provides the basic test procedure for evaluating the performance of a polyphase induction motor or generator of any size. Each revision of the standard since its 1964 introduction as an IEEE standard has been to keep the standard current with improvements in instrumentation, with improvements in test techniques, with increased knowledge in the art of measurements, and with the constant change in the needs and desires of the machine users and of those concerned with energy conservation and the like. Major portions of the document have been rearranged to accomplish this and the user is cautioned to check any external references to particular clauses of previous versions for the correct clause number in this version. Each individual test is defined and each efficiency test method is now covered in more detail and step-by-step instructions are presented. Standard symbols are now used for all quantities.

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Contents

IEEE Standard Test Procedure for Polyphase Induction Motors and Generators

1. Overview

1.1 Scope

This standard covers instructions for conducting and reporting the more generally applicable and acceptable tests of polyphase induction motors and generators. Many of the tests described may be applied to both motors and generators, as needed, and no attempt is made to partition the test procedure into clauses and subclauses that separately apply to motors or to generators. Whenever the term *motor* is used, it is to be understood that it may be replaced by the term *generator*, if applicable. Likewise, whenever *machine* is used, it may be replaced by either *motor* or *generator,* if applicable. Since polyphase power systems are almost universally three-phase systems, the equations in this standard have been written specifically for three phases. When the test is performed on other than three-phase power, the equations shall be modified appropriately.

1.2 Purpose

Instructions for conducting and reporting the more generally applicable and acceptable tests are covered to determine the performance and characteristics of polyphase induction motors and generators. Additional tests, not specified herein, may be required to satisfy specific research or application needs. These procedures shall not be interpreted as requiring the performing of any specific test in a given transaction.

2. References

This standard shall be used in conjunction with the following standards. When the following standards are superseded by an approved revision, the latest revision shall apply.

IEEE Std 43™-2000, IEEE Recommended Practice for Testing Insulation Resistance of Rotating Machinery.[1, 2]

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

IEEE Std 119™-1974, IEEE Recommended Practice for General Principles of Temperature Measurement as Applied to Electrical Apparatus.[3]

IEEE Std 120™-1989 (Reaff 1997), IEEE Master Test Guide for Electrical Measurements in Power Circuits.

3. General

3.1 Power Supply

3.1.1 Selection

Because the performance of an induction machine is dependent not only upon the value of the line voltage and frequency but also on the wave shape and the balance in magnitude and phase angle of the line voltages, correct data can be obtained only by careful measurement with accurate instrumentation and by employing a suitable source of power.

3.1.2 Waveform

The power supply shall provide balanced voltages closely approaching a sinusoidal waveform. The harmonic distortion coefficient, THD, shall not exceed 0.05. The THD is defined as shown in Equation (1).

$$THD = \frac{\sqrt{E^2 - E_1^2}}{E_1} \tag{1}$$

where

E_1 is the root-mean-square value of the fundamental of the voltage wave, in volts (V),

E is the total root-mean-square value of the voltage wave, in V.

3.1.3 Voltage unbalance

The voltage unbalance shall not exceed 0.5%. The percent voltage unbalance equals 100 times the maximum voltage deviation from the average voltage divided by the average voltage.

Example: With line voltages of 220 V, 215 V, and 210 V, the average voltage is 215 V, the maximum deviation from the average is 5, and the unbalance equals (100 × 5)/215 = 2.3%.

3.1.4 Frequency

For general testing, the frequency shall be within ±0.5% of the value required for the test being conducted, unless otherwise specified. Any departure from the specified frequency during the test directly affects the efficiency obtained with Efficiency Test Methods A, B, and B1. When these Methods are used, the frequency shall be within ±0.1% of the specified test value.

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[3] 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 (http://global.ihs.com/).

Rapid changes in frequency cannot be tolerated during testing because such variations affect not only the machine being tested, but also the output measuring devices. Variations in frequency during a test shall not exceed 0.33% of the average frequency.

3.2 Types of tests

3.2.1 Typical

Polyphase induction machines are normally given a routine test, but they may also be given additional tests.

For machine tests included in a typical routine test, refer to NEMA MG 1-2003 [B7][4] parts 12 and 20.

A typical form for reporting routine test data is shown in Annex B. A typical form for reporting additional test data is shown in Annex C.

3.2.2 Preliminary tests

The measurement of the winding resistance is commonly the first test performed. The resistance or the continuity of all windings and circuits should be measured at this time.

The ambient temperature is measured using the procedure of IEEE Std 119-1974. If the machine has embedded detectors, these may be used to confirm that the winding is at the ambient temperature.

3.2.3 Idle running tests

Running tests without load are made for the determination of core loss and windage and friction losses. Some other tests such as shaft voltage may also be performed under these conditions.

3.2.4 Tests with load

Tests with load are made for the determination of efficiency, power factor, speed, current, and temperature rise. Some of the miscellaneous tests outlined in Clause 8 are also made with load. For all tests with load, the machine shall be properly aligned and securely fastened. For readings to be used in performance determinations, the machine temperature rise shall be some value between 50% and 120% of the rated temperature rise. The usual procedure is to take readings at higher loads first and then follow with readings at lower loads.

3.2.5 Tests with rotor locked

It should be recognized that the testing of induction machines under locked-rotor conditions with polyphase power involves high mechanical stresses and high rates of heating. Therefore, it is necessary that

a) The mechanical means of securing the machine and locking the rotor are of adequate strength to prevent possible injury to personnel or damage to equipment.
b) The direction of rotation is established prior to the test.
c) The machine is at approximately ambient temperature before the test is started.

The current and torque readings shall be taken as quickly as possible, and, to obtain representative values, the machine temperature should not exceed rated temperature rise plus 40 °C. The readings for any point shall be taken within 5 seconds after voltage is applied.

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[4] The numbers in brackets correspond to those of the bibliography in Annex A.

3.2.6 Choice of tests

A complete list of tests covered by this standard is given in the table of contents. Alternate methods are described for making many of the tests suitable for different sizes and types of machines and different conditions. In some cases, the preferred method is indicated. Also see 6.2.1.

The schedule of factory and field tests that may be required on new equipment is normally specified by applicable standards or by contract specifications. The manufacturer's choice of method for factory or field tests on new equipment will govern in lieu of prior agreement or contract specification.

3.3 Standardized temperatures

3.3.1 Reference ambient temperature

The reference ambient temperature shall be 25 °C. If the ambient temperature during any performance test differs from the reference ambient, the performance determinations shall be corrected to an ambient temperature of 25 °C. The actual test temperatures shall be used in the separation of losses in the no-load test and in determining the stray-load loss by the direct method.

3.3.2 Specified temperature

The efficiency of the machine, at all loads, shall be determined based on the machine being at the specified temperature.

To accurately determine the values of some of the component losses with some efficiency test methods, it is necessary that the actual test temperatures be used in the analysis. If these test temperatures are not equal to the specified temperatures, appropriate corrections of the temperature dependent I^2R losses shall be made.

The specified temperature shall be determined by one of the following, which are listed in order of preference:

a) The specified temperature is the measured temperature rise by resistance from a rated load temperature test plus 25°C. Rated load is the rating identified on the nameplate at a 1.0 service factor.

b) The specified temperature is the measured temperature rise, as outlined in item a), on a duplicate machine. A duplicate machine is defined here as one of the same construction and electrical design.

c) When the rated load temperature rise has not been measured, the specified temperature is selected from Table 1 based on the class of the insulation system. If the rated temperature rise is stipulated to be that of a lower class of insulation system than that used in the construction, the temperature value listed for the lower insulation class shall be used as the specified temperature.

Preference c) shall not be used in Efficiency Test Method B; only preferences a) and b) are acceptable.

3.4 Use of this standard

After the test and test method are chosen, all necessary data may be obtained by following the instructions and precautions given in the subclause describing the test. Many of these subclauses include alternate methods for obtaining the necessary data. Unless otherwise specified, the manufacturer may choose the method best suited to the facilities available. It is anticipated that the development of improved practices and new equipment, such as electronic and automatic devices, will result in new or improved methods of carrying out the intent of this test standard. New or modified methods may be used as substitutes when their results have been shown to be reliable and consistent with those obtained by the methods given in this test procedure.

Table 1—Specified temperature for efficiency calculations when the machine rated load temperature is not measured

Class of insulation system	Temperature in °C (Total temperature including 25°C reference ambient)
A	75
B	95
F	115
H	130

3.5 Precautions

> **CAUTION**
>
> Many of the tests described in these procedures subject the machine to thermal and/or mechanical stresses beyond normal operating limits. To minimize the risk of damage to the machine, it is recommended that all tests be performed either under the manufacturer's supervision or in accordance with the manufacturer's recommendations.

4. Measurements

4.1 Electrical

4.1.1 RMS quantities

All voltage and current measurements are root-mean-square (rms) values, unless otherwise indicated.

4.1.2 Instrument selection

Calibrated, high-accuracy instrumentation and accessory equipment shall be used. Either analog or digital instruments may be used in testing. Factors affecting accuracy, particularly with nonelectronic analog instruments, are

a) Loading of the signal source
b) Lead calibration
c) Range, condition, and calibration of the instrument

Since instrument accuracy is generally expressed as a percentage of full scale, the range of the instrument chosen shall be as low as practical.

Electronic instruments are generally more versatile and have much higher input impedances than nonelectronic instruments. Higher input impedance reduces the need to make corrections for the current drawn by the instrument. However, high input impedance instruments can be more susceptible to noise.

Common sources of noise are

- Inductive or electrostatic coupling of signal leads to power systems
- Common impedance coupling or ground loops
- Inadequate common-mode rejection
- Conducted interference from the power line

Good practice requires using shielded twisted pairs for signal leads, grounding the shield at only one point, keeping the signal cables as far away as possible from power cables, and keeping the crossings at right angles when signal and power cables do cross. All exposed metal parts of instruments should be grounded for safety.

The instruments shall bear record of calibration, within 12 months of the test, indicating limits of the error no greater than ±0.5% of full scale for general testing or no greater than ±0.2% of full scale when the test results are for use with Efficiency Test Method B. When several instruments are connected in the circuit simultaneously, additional corrections of the instrument indication may be required.

When suitable automatic data acquisition systems or high-speed recorders are available, they may be used. Further information regarding the use of instruments is given in IEEE Std 120-1989.

4.1.3 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.

The errors of the transformers used shall not be greater than ±0.5% for general testing or not greater than ±0.3% when the test results are for use with Efficiency Test Method B. When instrument transformers and instruments for measuring voltage, current, or power are calibrated as a system, the errors of the system shall not be greater than ±0.2% of full scale when the test results are for use with Efficiency Test Method B.

4.1.4 Voltage

Each of the line-to-line voltages shall be measured with the signal leads connected to the machine terminals. If local conditions will not permit such connections, the difference between the voltage at the machine terminals and the point of measurement shall be evaluated and the readings shall be corrected. The arithmetic average shall be used in calculating machine performance from the test data.

4.1.5 Current

The line currents to each phase of the motor shall be measured, and the arithmetic average value shall be used in calculating machine performance from the test data.

4.1.6 Power

Power input to a three-phase motor or power output from a three-phase generator may be measured by two single-phase wattmeters connected as in the two wattmeter method, one polyphase wattmeter, or three single phase wattmeters. Power readings shall be corrected for meter losses if they are significant.

All power measurements and calculations, both electrical and mechanical, herein are in watts. On large machines it may be more practical to work with power quantities expressed in kilowatts. If the unit of measure is changed, take care that all affected values are properly converted.

4.2 Resistance

4.2.1 Instrument selection

Calibrated high-accuracy instrumentation shall be used. Either analog instruments (such as a Kelvin bridge) or digital instruments may be used in testing.

The instruments shall bear record of calibration, within 12 months of the test, indicating limits of the error no greater than ±0.2% of full scale.

When a suitable automatic data acquisition system is available, it may be used.

4.2.2 Resistance measurement

The procedures given in IEEE Std 118-1978 and IEEE Std 119-1974 should be used when measuring the resistance of the stator winding (and the rotor winding on wound-rotor machines).

4.3 Mechanical

4.3.1 Power

Mechanical power measurements shall be taken with the greatest care and accuracy. If a mechanical brake is to be used, the tare, if present, shall be carefully determined and compensated for. If dynamometer output measurements are used, coupling and bearing friction losses must be compensated for. Properly sized dynamometers should be used, such that the coupling, friction, and windage losses of the dynamometer (see the note below) measured at rated speed of the machine being tested should not be greater than 15% of the rated output of the machine being tested; and the dynamometer should be sensitive to a change of torque of 0.25% of the rated torque.

NOTE—A dynamometer is defined as a device for applying torque to the rotating member of the test machine. It is equipped with means for indicating torque and speed, and is not limited to a cradle base construction. An in-line torque transducer may be used to provide a direct measurement of torque at the test machine shaft.[5]

The errors of the instrumentation used to measure mechanical torque shall not be greater than ±0.2% of full scale.

4.3.2 Speed and slip

4.3.2.1 Instruments

Stroboscopic or digital tachometer methods shall be used to determine slip or speed. When a stroboscope is used to measure slip, the power supply for the stroboscope shall have the same frequency as the motor power supply.

When the speed is measured, the instrumentation used shall have an error of not greater than ±1.0 r/min of the reading.

4.4 Temperature

4.4.1 Methods of measuring temperatures

The temperature of various machine parts or coolant may be measured by the following:

a) Alcohol thermometer
b) Local temperature detector
c) Embedded detector
d) Winding resistance

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[5] Notes in text, tables, and figures are given for information only, and do not contain requirements needed to implement the standard.

The temperatures measured by any of these methods can deviate substantially from those determined by the other listed methods. Therefore, the temperatures so measured by one method shall not be interpreted in relation to standards written in terms of the other methods.

For general information, refer to IEEE Std 119-1974 and IEEE Std 1™-1986 [B5].

4.4.1.1 Alcohol thermometer

Alcohol thermometers are used to measure the temperature of accessible parts of the machine under test.

Temperatures taken by the alcohol thermometer method may be measured on the following parts:

a) Stator coils, in at least two places
b) Stator core, in at least two places
c) Ambient
d) Air discharged from frame or air discharge ducts, or internal coolant discharged to the inlet of coolers of machines with recirculating cooling system
e) Frame
f) Bearings (when part of the machine)

The alcohol thermometers should be located to obtain the highest temperature for the item being measured, except for ingoing and discharge air or other coolant temperature, for which they should be placed to obtain average values.

4.4.1.2 Local temperature detector

The local temperature of various parts of a machine can be determined using local temperature detectors such as

a) Thermocouples
b) Small resistance thermometers
c) Thermistors

The maximum dimension of the detecting element of these local temperature detectors should not exceed 5 cm.

These detectors can be used to measure temperatures in the same locations as alcohol thermometers, see 4.4.1.1, and are commonly used in areas on or within the machine that are not accessible to an alcohol thermometer. They are frequently installed as permanent parts of a machine and are available for use during tests.

The detecting element should be located on or in close thermal proximity to the part at which the local temperature is to be measured to obtain the highest temperature for that item, except for the incoming and discharge air or other coolant temperature, for which it should be placed to obtain the average value.

Specially designed instruments should be used with local temperature detectors to prevent the introduction of significant errors or possibly damaging the detector during the measurement. Because of the variety of materials used in these detectors, take care to insure the instrument selected is suitable for the specific material used in the detector or is matched to the resistance value when resistance thermometers are used. Many ordinary resistance measuring devices may not be suitable for use with resistance thermometers because of the relatively large current that may be passed through the resistance element while making the measurement.

4.4.1.3 Embedded detector

Embedded detectors, such as resistance temperature detectors (rtds) or thermocouples, are commonly used on large machines to monitor the winding temperature during operation and are available for use during machine testing. They are usually installed between coil sides within a stator slot. An rtd gives a reading that is the average of the temperature of the two abutting coil sides over the length of the sensing element. A thermocouple measures the temperature of the spot where the thermocouple junction is located between the two coil sides.

The precautions on the selection of instrumentation in 4.4.1.2 also apply here.

4.4.1.4 Winding resistance

The average temperature of a winding can be determined by comparing the resistance of the winding at the temperature to be determined with the resistance at a known temperature. This method utilizes the characteristic of the conductor material where, in the temperature range of interest, the winding resistance changes in direct proportion to the winding temperature. See 5.2.1.

4.4.2 Ambient temperature

The procedure of IEEE Std 119-1974 should be followed in measuring the ambient temperature.

4.5 Procedure

Whenever a series of increasing or decreasing readings of data are made, care should be taken in each case not to overrun the desired setting to avoid the introduction of hysteresis losses caused by a reversal in the direction of the test.

4.6 Safety

CAUTION

Because of the dangerous currents, voltages, and forces encountered, safety precautions shall be taken for all tests. No attempt is made here to list or review the manifold general safety precautions that are well established throughout industry. However, this standard includes special safety precautions applicable to the particular tests described. All tests should be performed by knowledgeable and experienced personnel.

5. Machine losses and tests for losses

This clause identifies the losses of an induction machine and describes tests and calculations to be used to determine these losses and the machine performance characteristics. The results of these tests are used in making the efficiency and performance determinations of Clause 6. All tests and procedures of this clause are not required in all of the efficiency analysis methods. Refer to the specific efficiency test method of interest in Clause 6.

Alternate test methods are presented where appropriate.

5.1 Types of losses

The losses of an induction machine include:

- Stator I^2R loss, see 5.2
- Rotor I^2R loss, see 5.3
- Friction and windage loss, see 5.5.4
- Core loss, see 5.5.5
- Stray-load loss, see 5.7
- Brush-contact loss, see 5.10

Other individual tests or procedures are required to support some of the efficiency test methods. These include:

- Shaft power, see 5.6.1.1
- Dynamometer correction, see 5.6.1.2
- Equivalent circuit, see 5.9
- Temperature test, see 5.8

5.2 Stator I^2R loss

For a three-phase machine, the stator I^2R loss, P_{SIR}, in watts is as shown in Equation (2).

$$P_{SIR} = 1.5I^2R = 3I^2R_1 \tag{2}$$

where

I	is the measured or calculated current per line terminal, in amperes (A),
R	is the dc resistance, in ohms, between any two line terminals—corrected to the appropriate temperature, if required (see 5.2.1),
R_1	is the per phase dc resistance, in ohms (see 5.9).

5.2.1 Resistance correction for temperature

Some of the test analyses require that the winding resistance be adjusted or corrected to another temperature. With the winding resistance value, R_a, available at a known temperature, t_a, the resistance value at any other temperature, t_b, can be determined using Equation (3).

$$R_b = \frac{R_a(t_b + k_1)}{t_a + k_1} \tag{3}$$

where

R_a	is the known value of winding resistance, in ohms, at temperature t_a,
t_a	is the temperature, in °C, of winding when the resistance R_a was measured,
t_b	is the temperature, in °C, to which the resistance is to be corrected,
R_b	is the winding resistance, in ohms, corrected to the temperature t_b,
k_1	is 234.5 for 100% IACS conductivity copper, or 225 for aluminum, based on a volume conductivity of 62%.

For other winding materials, a suitable value of k_1 (inferred temperature for zero resistance) shall be used.

When a winding resistance value is calculated for a different temperature, t_a and t_b shall be based on the same method of measure. See 4.4. When any winding I^2R loss is determined at a temperature, the calculation shall use a winding resistance value that is based on the winding being at an average (or uniform) temperature. The specified temperature, the temperature at shutdown (measured by resistance) and the temperature when the cold resistance is obtained are all average temperatures. It may not be possible to obtain average temperature readings during some tests (such as during a load test) and special procedures for evaluating the average winding temperature using local detector readings may be necessary. One such procedure is utilized in 6.4.2.4.

5.3 Rotor I^2R loss

The rotor I^2R loss, including brush-contact losses for wound-rotor machines, shall be determined from the slip using Equation (4) or Equation (5) as follows:

$$\text{motor rotor } I^2R \text{ loss } = (\text{measured stator input power} - \text{stator } I^2R \text{ loss} - \text{core loss}) \times s \tag{4}$$

$$\text{generator } I^2R \text{ loss } = (\text{measured stator output power} + \text{stator } I^2R \text{ loss} + \text{core loss}) \times s \tag{5}$$

where

s is slip, in per unit (p.u), with synchronous speed as base speed, see Equation (8).

All power items are in watts (W).

5.3.1 Slip

The slip speed, in r/min, can be measured directly by stroboscopic means or it can be calculated from the measured speed. This value then must be converted to a numeric or per unit value for use in the analyses.

The slip speed is the difference between synchronous speed and measured speed, in r/min [see Equation (6)].

$$\text{slip speed } = n_s + n_t \tag{6}$$

where

$$n_s = 120 \times \frac{f}{p} \tag{7}$$

and

n_s is the synchronous speed, in r/min,
n_t is the measured speed, in r/min,
f is the line frequency, in hertz,
p is the number of poles.

Slip expressed as a per unit quantity is

$$s = \frac{\text{slip speed (in r/min)}}{\text{synchronous speed (in r/min)}} \tag{8}$$

NOTE—It is assumed the number of poles is known. If not, the number of poles can be determined by using no-load test data and by rearranging Equation (7) to solve for p. (Multiply the input frequency times 120 and then divide by the measured idle speed.) This calculation will result in a value very near an even number (0% to 4% high). Round this value to the nearest lower even number (such as, 2, 4, 6, etc.) and this is the number of poles in the machine.

5.3.2 Slip correction for temperature

The slip, in p.u., is directly related to the rotor resistance. Thus, the slip can be corrected for temperature using the same basic relationship as for resistance and temperature. The corrected value of slip is used in determining the rotor I^2R loss in the final adjustments when using Efficiency Test Methods B, B1, and C. Use Equation (9) to correct the test slip measurements to the specified stator temperature.

$$s_s = \frac{s_t(t_s + k_1)}{(t_t + k_1)} \tag{9}$$

where

s_s is the slip, in p.u., corrected to specified stator temperature, t_s,
s_t is the slip, in p.u., measured at stator winding temperature, t_t,
t_s is the specified temperature for resistance correction, in °C, see 3.3.2,
t_t is the observed stator winding temperature during load test, in °C,
k_1 is 234.5 for 100% IACS conductivity copper, or 225 for aluminum, based on a volume conductivity of 62% (*based on rotor conductor material*).

NOTES:

1—For other rotor winding materials, a suitable value of k_1 (inferred temperature for zero resistance) shall be used.

2—The values for t_s and t_t shall be based on the same method of measurement of temperature, see 5.2.1.

5.4 Winding resistance—cold

With the machine at ambient temperature, measure the terminal-to-terminal winding resistance with the machine connected in the configuration to be used in the efficiency testing. Measure and record all combinations, i.e., T1-T2, T2-T3, and T3-T1, to assure that the specific precise value needed in further analyses will be available. Also measure and record the ambient temperature. See 3.2.2.

5.5 No-load test

This test is performed by running the machine as a motor at rated voltage and frequency with no connected load. When separation of no-load losses is to be accomplished, run this test and read temperature, voltage, current, and power input at rated frequency and at voltages ranging from 125% of rated voltage down to the point where further voltage reduction increases the current.

5.5.1 Bearing loss stabilization

Some motors may experience a change in friction loss until the bearings reach a stabilized operating condition. In grease lubricated antifriction bearings, stabilization will not occur until there is no excess grease present in the path of the moving parts. This may require a number of hours of running to completely stabilize the no-load input power. Stabilization can be considered to have occurred whenever the power input at no-load does not vary by more than 3% between two successive readings at the same voltage at half-hour intervals. This bearing loss stabilization test may not be necessary if a temperature test has been performed prior to no-load testing.

5.5.2 No-load current

The average of the line currents at rated voltage is the no-load current.

5.5.3 No-load losses

The measured input power is the total of the losses in the motor at no-load. These losses consist of the stator I^2R, friction (including brush-friction loss on wound-rotor motors), windage, and core losses.

5.5.4 Friction and windage

The friction and windage loss may also be determined by performing a linear regression analysis using three or more lower points of the power versus voltage squared curve. To determine the friction and windage loss, subtract the stator I^2R loss (at the temperature of the test) from the total losses (i.e., input power) at each of the test voltage points and plot the resulting power curve versus voltage, extending the curve to zero voltage. The intercept with the zero voltage axis is the friction and windage loss. This intercept may be determined more accurately if the input power minus stator I^2R loss is plotted against the voltage squared for values in the lower voltage range.

5.5.5 Core loss

The core loss, P_h, at each test voltage is obtained by subtracting the value of friction and windage loss (determined in 5.5.4) from the input power minus stator I^2R loss (determined in 5.5.4). A plot of core loss versus voltage can be constructed for use in determining the core loss at any desired voltage.

5.6 Load test

Most of the efficiency test methods require that a load test be performed either to directly determine the efficiency as in Efficiency Test Method A or to determine the stray-load loss as in Efficiency Test Methods B, B1, and C. The machine is coupled to a load machine and is subjected to loads at four load points approximately equally spaced between not less than 25% and up to and including 100% load, and two load points suitably chosen above 100% load but not exceeding 150% load. A spread in load test points is necessary to determine the efficiency accurately over the entire load range of the machine and more than six load points may be used if desired.

Readings of electrical power, current, voltage, frequency, speed or slip, torque, stator winding temperature or stator winding resistance, and ambient temperature shall be obtained at each load point. In loading the machine, start at the highest load value and move in descending order to the lowest.

The common loading means are as follows:

- Dynamometer. See 5.6.1.
- Direct loading without torque measurement. See 5.6.2.
- Duplicate machine loading. See 5.6.3.

5.6.1 Dynamometer loading

For this test, the machine is loaded by means of a mechanical brake or dynamometer (see 4.3.1) and tested as described in 5.6.

This test should be performed as quickly as possible to minimize temperature changes in the machine during testing.

For Efficiency Test Method B, the temperature of the stator winding shall be within 10 °C of the hottest temperature reading recorded during the rated load temperature test on this or the duplicate machine prior to the start of recording data for this test.

5.6.1.1 Mechanical power

The shaft power, in W, of the machine under test at each load point is obtained from Equation (10) using the test values of torque and speed. The torque may require correction for dynamometer losses. See 5.6.1.2.

$$P = \frac{2xn_tT}{60} = \frac{n_tT}{k_2} \tag{10}$$

where

P is shaft power, in watts (W),
n_t is the measured speed or the speed calculated using measured slip, in r/min,
k_2 is 9.549 for torque in Newton meters (N•m),
T is the torque[6], in N•m. See Equation (11) if dynamometer correction is required.

$$T = T_t \pm T_D \tag{11}$$

where

T_t is a measured machine shaft torque, in N•m,
T_D is the dynamometer correction from Equation (12), in N•m.

NOTE—In Equation (11), use the plus sign for motoring and the minus sign for generating. The terms *motoring* and *generating* refer to the action of the machine under test.

5.6.1.2 Dynamometer correction

A dynamometer no-load test combined with a machine no-load test can be used to determine the dynamometer correction to compensate for coupling and bearing friction losses of the dynamometer. This test is not generally necessary when the load on the test machine is measured using a torque transducer in line with the shaft of the machine because the low coupling losses do not significantly affect efficiency. The machine is operated as a motor at rated voltage while coupled to the dynamometer and all electrical power removed from the dynamometer. The electrical input power, voltage, current, slip or speed, torque, and stator winding resistance or stator winding temperature shall be recorded. The machine is then uncoupled from the dynamometer and operated at no load at rated voltage with the electrical input power, voltage, current, slip or speed, and stator winding resistance or stator winding temperature again recorded. Test data from a no-load test point at rated voltage (see 5.5) may be used for the no-load data when it is not practical to uncouple the machine from the dynamometer for this test. The dynamometer correction, in N•m, is determined from Equation (12).

$$T_D = k_2 \times \frac{P_A - P_B}{n_A} - T_A \tag{12}$$

where

$$P_A = (P_{inA} - P_{SIRA} - P_h) \times (1 - s_A) \tag{13}$$

$$P_B = (P_{inB} - P_{SIRB} - P_h) \tag{14}$$

and

---

[6] For other units of measure, see Annex D.

T_D is the correction to be applied the load torque before performing the power calculation of 5.6.1.1,

P_{inA} is input power, in W, when the machine under test is operated as a motor when coupled to a dynamometer with the dynamometer armature circuit open, (Test A),

P_{SIRA} is the stator I^2R loss, in W, during Test A,

s_A is slip, in p.u., during Test A,

T_A is the torque, in N·m, registered by the dynamometer during Test A,

n_A is the measured speed or the speed calculated using measured slip, in r/min, during Test A,

P_{inB} is the input power, in W, during a no load test at rated voltage, (Test B),

P_{SIRB} is the stator I^2R loss, in W, during a no load test at rated voltage, (Test B),

P_h is the core loss, in W, during a no load test at rated voltage,

k_2 is 9.549 for torque in N·m.

5.6.2 Direct loading with no torque measurement

To obtain the required data in Efficiency Test Method E, it is necessary to couple, belt, or gear the machine to a variable load and then perform the test as described in 5.6. A reading of torque at each load point is not required.

The stator winding resistance for each load point can be estimated by comparing the temperature rise measured by an embedded temperature detector, a temperature sensor located on the stator coil end, or the air outlet temperature rise, with corresponding temperature rise measurements obtained as steady-state values during a temperature test. When no temperature test is performed on this or on a duplicate machine, the calculations in the efficiency analysis are made with the stator winding resistance corrected to the total specified winding temperature assumed for the test. See 3.3.2, item c).

5.6.3 Duplicate machine loading

The load test for Efficiency Test Method C utilizes two duplicate machines coupled together. Varying the frequency of the voltage applied to one machine controls the load level and the direction of power flow between machines. This procedure is presented in 6.6.

5.7 Stray-load loss

The stray-load loss is that portion of the total loss in a machine not accounted for by the sum of the friction and windage loss, the stator I^2R loss, the rotor I^2R loss, and the core loss.

5.7.1 Indirect measurement

The stray-load loss is determined indirectly by measuring the total losses, and subtracting from these losses the sum of the friction and windage, core loss, stator I^2R loss, and rotor I^2R loss. The remaining value is the stray-load loss. The indirect measurement procedure is used in Efficiency Test Methods B, B1, C, and C/F (see 6.4, 6.5, 6.6, and 6.9).

5.7.2 Direct measurement

Direct measurement of the stray-load loss is used in efficiency methods E, F, and E/F (see 6.7, 6.8, and 6.9). The fundamental frequency and the high-frequency components of the stray-load loss are determined and the sum of these two components is the total stray-load loss.

5.7.2.1 Stray-load loss at fundamental frequency

The stray-load loss occurring at fundamental frequency is determined by applying balanced polyphase voltage to the stator-winding terminals with the rotor removed. The electrical input minus the stator I^2R loss at test temperature is equal to the fundamental frequency stray-load loss. During this test, bearing brackets and other structural parts in which current might be induced shall be in place. The currents used in making this test and that described in 5.7.2.2 are identified as I_t, with values established by Equation (15) for magnitudes covering the range of loads from 0.25 to 1.5 times rated load, as indicated by the appropriate test procedure. Vary the applied voltage to obtain the established currents and record input power and current and the winding temperature.

$$I_t = \sqrt{(I^2 - I_0^2)} \tag{15}$$

where

I_t is the value of stator winding current, in A, during stray-load loss test,
I_0 is the value of no-load current, in A (see 5.5.2.),
I is the operating value of stator line current, in A, for which stray-load loss is to be determined.

5.7.2.2 Stray-load loss at high frequency

The stray-load loss occurring at high frequencies is determined by a reverse rotation test. With the motor completely assembled, apply balanced polyphase voltages at rated frequency at the stator winding terminals. The rotor is then driven by external means at or near synchronous speed in the direction opposite to the stator field rotation and the electrical input to the stator winding is measured.

CAUTION

To prevent overheating during this test of machines with unidirectional cooling systems, it is recommended that such machines be driven by an external means at or near synchronous speed in the normal direction for proper ventilation and that the power connections to the stator be reversed to have the stator field rotation opposite to that of the mechanical rotation. Record the electrical input to the stator during the test.

The mechanical power required to drive the rotor is measured both with and without current in the stator winding. A balanced polyphase voltage is applied to the stator winding to obtain the same values of current magnitude as used in 5.7.2.1. The magnitude of the currents must be the same. For wound-rotor motors, the rotor terminals shall be short-circuited. At each current point, measure and record the mechanical power to drive the motor, the electrical input power and current, and the winding temperature. Record mechanical power input at zero input current.

NOTE–The low power factors encountered during the tests specified in 5.7.2.1 and 5.7.2.2 make it imperative that phase angle error corrections be applied to all wattmeter readings. Refer to IEEE Std 120-1989.

5.7.2.3 Stray-load loss calculation

The stray-load loss is determined by combining the above fundamental frequency and the high-frequency components. The stray-load loss, P_{SL}, in W, is shown in Equation (16).

$$P_{SL} = P_{SLs} + P_{SLr} \tag{16}$$

where

P_{SLs} = (P_s – stator I^2R loss), in W, and is the fundamental frequency stray-load loss,

P_{SLr} $= (P_r - P_m) - (P_{rr} - P_{SLs} -$ stator I^2R loss), in W, and is the high-frequency loss,
P_m is the mechanical power, in W, required to drive rotor without voltage being applied at stator winding terminals,
P_r is the mechanical power, in W, required to drive rotor with voltage applied at stator winding terminals,
P_{rr} is the electrical input, in W, to stator winding during reverse-rotation test,
P_s is the electrical input, in W, to stator winding with rotor removed.

Stator I^2R loss shall be calculated as in Equation (2) using the current and resistance at each point.

5.7.2.4 Smoothing the test data

Smooth the raw data; $(P_r - P_m)$, P_s and P_{rr}; from the tests of 5.7.2.1 and 5.7.2.2 using a series of three regression analyses. Each regression analysis is of the log of a test power vs. the log of the test current. The result of these analyses is shown in Equation (17) through Equation (19).

$$P_r - P_m = A_1(I_t)^{N_1} \tag{17}$$

$$P_s = A_2(I_t)^{N_2} \tag{18}$$

$$P_{rr} = A_3(I_t)^{N_3} \tag{19}$$

where

A is the y intercept on a log-log plot (a constant),
N is the slope on a log-log plot (approximately 2),
I_t is the observed line current during the stray-loss test, in amperes.

If the data are accurate, each curve will conform to a square-law relationship between power and current. Thus, the correlation factor from the regression and exponent for each curve both serve as indicators of data accuracy.

5.7.2.5 Calculating stray-load loss at a specified point

Determine an approximate value of rotor 2current I'_2 corresponding to the rated value of stator line current, I, as in Equation (20).

$$I'_2 = \sqrt{I^2 - I_0^2} \tag{20}$$

where

I is the rated value of stator line current, in A,
I_0 is the value of no-load stator current, in A.

Using the value of rotor current I'_2, calculate a value of stray-load loss P'_{SL} for three-phase machines as follows in Equation (21):

$$P'_{SL} = A_1(I'_2)^{N_1} + 2A_2(I'_2)^{N_2} - A_3(I'_2)^{N_3} - 3 \times (I'_2)^2 \times (2R_{1s} - R_{1r}) \tag{21}$$

where

P'_{SL} is the value of stray-load loss, in W, for approximate value of rotor current corresponding to rated load,
I'_2 is the approximate value of rotor current, in amperes, corresponding to rated load from Equation (20),
R_{1s} is the stator resistance per phase, in ohms, during the rotor removed test at test temperature (see 5.7.2.1),
R_{1r} is the stator resistance per phase, in ohms, during the reverse rotation test at test temperature (see 5.7.2.2).

NOTE—The resistance values above are per phase values that are equal to one half of the line-to-line values.

The value of stray-load loss, P_{SL}, for any load point is calculated as shown in Equation (22).

$$P_{SL} = P'_{SL}\left(\frac{I_2}{I'_2}\right)^2 \quad (22)$$

The value of rotor current for each load point to be considered in the efficiency analysis is determined by Equation (23).

$$I_2 = \sqrt{I^2 - I_0^2} \quad (23)$$

where

I is the value of stator line current, in A, for which stray-load loss is to be determined,
I_0 is the value of no-load current, in A.

5.7.3 Alternate direct method for wound-rotor motors

This method is used with Efficiency Test Methods E, F, and E/F (see 6.7, 6.8, and 6.9). In this method, the rotor is excited with direct current, and the stator winding terminals are short-circuited with ammeters included to read the stator current. The rotor is driven by external means at or near synchronous speed. The rotor excitation is adjusted until the current circulating in the stator winding has the value for which a stray-load loss determination is desired. The mechanical power required to drive the rotor with excitation, P_r, and without excitation, P_m, is measured and the stray-load loss, P_{SL}, is calculated as shown in Equation (24).

$$P_{SL} = P_r - P_m - \text{statorwinding} I^2R \text{ loss} \quad (24)$$

If six load points are used, the accuracy can be improved by plotting stray-load loss vs. stator winding current squared and by following a smoothing procedure similar to that used in 5.7.2.4. The stator I^2R in Equation (24) is at the temperature during the test.

5.7.4 Assumed stray-load loss

An assumed value of stray-load loss is used with Efficiency Test Methods El, Fl, and El/Fl (see 6.7, 6.8, and 6.9). If the stray-load loss is not measured and it is acceptable by applicable standards or by contract specifications, the value of stray-load loss at rated load may be assumed to be the value as shown in Table 2.

For other than rated load, it shall be assumed that the stray-load loss, P_{SL}, is proportional to the square of the rotor current and a value can be calculated using Equation (22) with P'_{SL} equal to the assumed value from

Table 2—Assumed values for stray-load loss

Machine rating kW	Stray-load loss percent of rated load
1–90	1.8%
91–375	1.5%
376–1850	1.2%
1851 and greater	0.9%

Table 2, I'_2 equal to the rotor current corresponding to rated load, and I_2 being the rotor current at the load where the stray-power loss is to be determined.

5.8 Temperature test

5.8.1 Purpose

Temperature tests are made to determine the temperature rise of certain parts of the machine above the ambient temperature when running under a specified loading condition. Subclauses 5.8.2 through 5.8.5 are guides for the test and for the treatment of the data.

5.8.2 General instructions

The machine shall be shielded from air currents coming from pulleys, belts, and other machines. A very slight current of air may cause great discrepancies in the temperature test results. Conditions that result in rapid change of ambient air temperature shall not be considered satisfactory for temperature tests. Sufficient floor space shall be provided between machines to allow free circulation of air.

5.8.2.1 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.

5.8.2.2 Temperature of rotors and other parts of totally enclosed machines

The temperature of rotors and other parts of totally enclosed machines, for which the thermometer method is used, shall be obtained after shutdown by applying the thermometer to the hottest parts that can be made quickly accessible by removing covers.

5.8.3 Loading method

The loading method for making the temperature test shall be one of the following:

a) Actual loading method

b) Primary-superposed equivalent method

c) Forward stall equivalent method

5.8.3.1 Actual loading method

The actual loading method is one in which the machine is loaded as a motor or generator under the rated (or desired) condition.

5.8.3.2 Primary-superposed equivalent loading method

Primary-superposed equivalent loading method is one in which the machine is operated at no-load from a main power source and with a low-voltage auxiliary power of different frequency superposed. A typical configuration is shown in Figure 1. The phase rotation of the auxiliary power shall be chosen to have the same direction as that of the main power.

Generally, temperature rises are determined by running with the superposed power supplied at a frequency 10 Hz below rated frequency, and with the voltage so adjusted that the current to the machine is equal to the rated value.

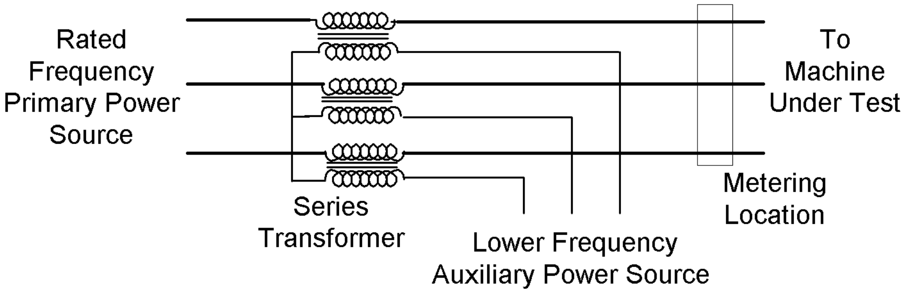

Figure 1—Typical connection for superposed equivalent loading

NOTES

1–When the loading for the temperature test is the superposed equivalent loading method, the slip loss does not apply, and a tested value of rotor I^2R loss, per 5.3, cannot be obtained. Therefore, when equivalent loading is used, calculated rotor I^2R shall be used in determining efficiency by the segregated loss method. See 6.6.

2–Inasmuch as there are oscillatory torques applied to the stator and rotor of the machine supplied with power at two different frequencies, vibration will be abnormal during this condition, and normal criteria for vibration do not apply. Vibration should be monitored and compared against acceptable limits for the machine being tested. After the machine has been heated, the auxiliary frequency can be removed and vibration can be measured with rated frequency and voltage applied to determine the vibration of the machine operating at normal running temperature. The machine will cool rapidly after removing the auxiliary frequency. Therefore, temperature should be monitored by thermocouple to ensure that vibration is measured while the motor is within 25% of normal operating temperature.

5.8.3.3 Forward stall equivalent loading method

The forward stall (also known as forward short circuit) loading method is one in which the machine to be tested is driven at rated speed in its normal direction of rotation by an auxiliary drive motor while the terminals of the motor under test are connected to a reduced voltage fixed frequency supply with phase sequence selected to give rotation in the normal direction. Generally, the supply frequency is 20% to 25% less than the machine rated (nameplate) frequency. The auxiliary drive motor should have a power rating of at least 10% that of the motor under test.

With the auxiliary drive motor driving the coupled system at rated speed, the voltage at the machine terminals is adjusted until the line current equals the rated current. The machine under test is then operating as an induction generator with a slip of approximately –25% (–0.25 p.u.).

With the reduced voltage on the machine, the stator iron losses are lower than under actual loading conditions of 5.8.3.1. To compensate for this difference, the test is supplemented by two no-load temperature tests at rated frequency, one at rated supply voltage and one at the stator voltage used during the forward stall test. The difference between the stator temperature rises in these two tests is added to temperature rise measured during the forward stall test and the resultant rise is to be considered as the total temperature rise.

NOTE—During the load application phase, as the supply voltage is raised from zero, the current should first reduce and then reverse. If the current increases without this initial reversal, the phase sequence of the machine relative to the supply is incorrect. If this occurs, stop the test, change the phase sequence, and restart the test.

5.8.4 Procedure

The machine may be loaded by one of the methods outlined in 5.8.3. The loading may be determined by direct measurement of output or input.

A machine having multiple ratings (such as a multispeed or oil-well service machine) shall be tested at the rating that produces the greatest temperature rise. Where this cannot be predetermined, the machine shall be tested at each rating.

A dual-frequency machine may be tested at whichever frequency is available. If both frequencies are available, it should be tested at the frequency that results in the maximum temperature rise.

Unless otherwise stipulated by the efficiency test method, a machine having a service factor greater than 1.0 shall be tested at the service factor load to establish that the machine meets insulation class temperature limits, except when temperature rise at a specified loading forms part of the machine rating. However, the temperature rise at 1.0 service factor shall be used in calculating machine performance in accordance with 3.3.2.

When the temperature test is at the service factor load rather than rated load (1.0 service factor), the temperature rise by resistance of the motor at rated load can be derived by varying the temperature rise by the square of the current. For the efficiency calculations, the total temperature (specified temperature) will be the rise at rated load plus 25 °C.

When the analysis shows that the temperature test was performed near but not at the rated load, Equation (25) also may be used to adjust the test temperature rise to a rated load temperature rise. If the test load is below rated load, this adjustment must be made.

$$Temperature\ Rise_{\text{rated}} = Temperature\ Rise_{\text{test}} \times \left[\frac{I_{\text{rated}}}{I_{\text{test}}}\right]^2 \tag{25}$$

5.8.4.1 Initial conditions

Temperature tests on continuously rated machines can be started with the machine at any temperature less than rated temperature. Unless otherwise specified, a test on a short-time rated machine shall commence only when machine parts are within 5 °C of the ambient temperature.

5.8.4.2 Permissible overloading

On continuously-rated machines, when a long time is required to attain steady temperature, reasonable (25% to 50%) overloads during the preliminary heating period are permissible in order to shorten the time of test. Any overload shall be removed before the temperature goes above the expected final temperature.

5.8.4.3 Temperature measurement

The machine should be equipped with devices to measure the temperature of the windings, the stator core, the incoming cold coolant, and the exhaust hot coolant. Each method of measurement, see 4.4, is best suited for particular parts of machine. Thus, in a given test, it may be desirable to use all four methods to measure the temperature in the various parts of the machine.

Temperatures taken by the alcohol thermometer method (see 4.4.1.1) may be measured during the temperature tests and, if specified, after shutdown.

Local temperature detectors (see 4.4.1.2) may be used to measure the temperature of various parts of the machine during the temperature test. When several local temperature detectors are used to measure the winding temperature, the temperature measurements of all should be recorded, with the maximum of these values reported as the temperature of the winding by local detector. Readings after shutdown are not normally required

Temperatures of the windings of machines equipped with embedded detectors should be determined by the embedded-detector method (see 4.4.1.3) during the temperature test. Temperature measurements of all embedded detectors shall be recorded, and the maximum of these values shall be reported as the temperature of the winding by embedded detector. Readings after shutdown are not normally required.

The temperature of the stator (and rotor of wound-rotor machines) winding shall be determined by the winding resistance method (see 4.4.1.4) after shutdown (see 5.8.4.4 and 5.8.4.5). The resistance may be measured between any two line terminals for which a reference value of resistance has been measured at a known temperature. If equipment is available to measure the winding resistance during the temperature test, this may be used if the results have the necessary accuracy.

Other temperature sensing devices on the machine such as bearing and/or lubricant temperature detectors should also be noted and recorded.

5.8.4.4 Termination of test

The test shall be continued for the specified time (for machines not continuously rated), or until constant temperature rises have been reached. For continuously rated machines, readings of machine input, machine output (as applicable), and all temperatures (including ambient temperature) shall be taken at intervals of 30 minutes or less. For noncontinuously rated machines, readings shall be taken at intervals consistent with the time rating. For continuous rated machines, the temperature test shall continue until there is 1 °C or less change in temperature rise above the ambient temperature over a 30-minute period.

If the winding resistance is measured during the temperature test, see 5.8.4.3; take a reading at the time of shutdown, provided the results have the necessary accuracy. Measurements after shutdown are not required.

5.8.4.5 Resistance at shutdown

The winding resistance shall be measured after shutdown and this shall be used to determine the final temperature of the machine and its temperature rise. This measurement requires a quick shutdown of the machine at the end of the temperature test and quick application of the leads from the resistance measuring device. A carefully planned procedure and an adequate number of people are required to obtain readings soon enough to give reliable data.

If the initial resistance reading is obtained within the time interval indicated in Table 3, this reading is accepted as the resistance measurement. If the initial resistance reading cannot be made within the time delay given by the table, it shall be made as soon as possible, and additional resistance readings shall be taken at intervals of 30–60 seconds for a minimum of 10 readings.

Table 3—Maximum time delay in resistance measurements

Machine rating		Time delay after switching off power (seconds)
KVA	**kW**	
50 or less	38 or less	30
Above 50 to 200	Above 38 to 150	90
Above 200	Above 150	120

A curve of these readings shall be plotted as a function of time, and shall be extrapolated to the time delay given by Table 3 for the rating of the machine. A semi-logarithmic plot is recommended, in which resistance is plotted on the logarithmic scale. The value of resistance thus obtained shall be considered as the resistance at shutdown. If successive measurements show increasing resistance after shutdown, the highest value shall be taken. Where the first reading cannot be taken within twice the time delay given by Table 3, the time shall be subject to agreement.

5.8.4.6 Care in measurement

Extreme care shall be taken to secure accurate resistance measurements because a small error in measuring resistance will cause a comparatively large error in determining the temperature.

5.8.5 Temperature rise

When the machine is ventilated by the immediately surrounding air, the temperature rise is the observed machine temperature minus the ambient temperature. When the machine is ventilated by air obtained from a remote source or a heat exchanger, the temperature rise is the observed machine temperature minus the temperature of the air entering the machine or exiting the heat exchanger when part of the machine.

Machines may be tested at any altitude not exceeding 1000 m and with cooling air temperatures between 10°C and 40°C without correction of temperature rise.

NOTE—At higher altitudes, the temperature rise will be greater than at sea level. While an exact conversion is not available, a commonly used method allows for the influence of altitude. For each 100 m above 1000 m, the temperature rise is reduced by 1% to obtain the rise expected at sea level.

5.8.5.1 Calculation of temperature

The temperature of the winding, using the winding resistance, is calculated using Equation (26).

$$t_t = \left(\frac{R_f}{R_b} \times (t_b + k_1)\right) - k_1 \qquad (26)$$

where

t_t is the total temperature of winding, in °C, when R_t was measured,
R_t is the resistance measured during test, in ohms,
R_b is the reference value of resistance, in ohms, previously measured at known temperature $t_{b,}$
t_b is the temperature, in °C, of winding when reference value of resistance R_b was measured,
k_1 is 234.5 for 100% International Annealed Copper Standard (IACS) conductivity copper, or 225 for aluminum, based on a volume conductivity of 62%.

For other winding materials, a suitable value of k_1 (inferred temperature for zero resistance) shall be used.

The temperature obtained by using Equation (26) is the total temperature of the winding at the time of the test. If this is the usable shutdown resistance reading, the results will be the total temperature of the winding at the test ambient temperature. If this ambient differs from the reference ambient, see 3.3.1, adjust the total temperature by subtracting the test ambient from the calculated total temperature and then adding 25 °C to the difference value just obtained. If the temperature test was at the rated load, the resultant sum is the total winding temperature in a 25 °C ambient and is the specified temperature to be used in the efficiency analysis. See 3.3.2 a). If the test was at other than rated load, see 5.8.4 for the procedure to correct to rated load.

5.9 Equivalent circuit

The operating characteristics in Efficiency Test Methods F and F1 (see 6.9) are calculated based on the equivalent circuit of an induction machine shown in Figure 2. This circuit is also used in determining the rotor current used in determining the stray-load losses used in other efficiency test methods.

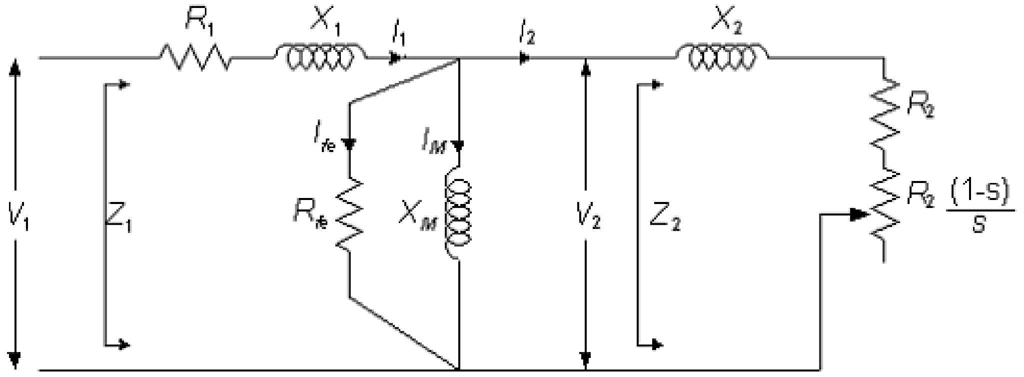

Figure 2—Equivalent circuit

The machine quantities associated with the equivalent circuit and with Equation (27) through Equation (58) are as follows:

V_1	is phase voltage, in V
V_2	is rotor phase voltage referred to the stator, in V
f	is frequency, in Hz
I_1	is line or stator current, in A
I_2	is rotor current referred to stator, in A
I_m	is magnetizing current, in A
I_{fe}	is core loss current, in A
m	is number of phases
R_1	is stator resistance, in ohms
R_2	is rotor resistance referred to stator, in ohms
R_{fe}	is core loss resistance, in ohms
G_{fe}	is core loss conductance, in siemens
X_1	is stator leakage reactance, in ohms
X_2	is rotor leakage reactance referred to stator, in ohms

X_M is magnetizing reactance, in ohms
B_M is magnetizing susceptance, in siemens
P is power, in watts
P_h is core loss, in watts
P_f is friction and windage loss, in watts
Q is reactive power, in vars
Z is impedance per phase, in ohms
Z_2 is rotor impedance per phase referred to stator, in ohms
s is slip in p.u.

Subscripts are as follows:
0 = quantities pertaining to no-load
L = quantities pertaining to impedance test

NOTES:

1—For three-phase machines, the per phase wye stator resistance is one-half of the terminal-to-terminal resistance.

2—For three-phase machines, the wye phase voltage, V_1, is the line-to-line voltage divided by $\sqrt{3}$.

The machine parameters in the equivalent circuit are derived from test data recorded during a no-load test of 5.5 and one of the impedance tests described in 5.9.1. The equivalent circuit represents one phase of a three-phase, wye-connected machine and is usable even if the machine under test has a delta internal connection. Rotor voltage, current, resistance, and reactance values all are referred to the stator and are not true rotor values but can be used throughout this standard wherever rotor parameters are specified.

Accurate prediction of machine characteristics in the normal operating range will depend primarily upon the closeness by which R_2 represents the actual rotor resistance to currents of low frequency and, secondarily, upon the closeness by which X_2 represents the actual rotor leakage reactance to currents of low frequency. Therefore, the most careful procedure during testing to determine the rotor characteristics at low frequency is imperative. Calculation results may be reported on Form 9.14.

5.9.1 Impedance tests

Readings of voltage, current, electrical input power, and stator resistance or stator winding temperature are to be taken at one or more frequencies, voltages, and/or loads. These data are referred to as the impedance data. If the machine being tested has a wound rotor, the rotor is to be short-circuited for the test.

The tests for reactance shall be conducted at rated load current. It is important that the value of reactance used in the equivalent circuit calculation is at the correct value of saturation and deep bar effect; otherwise, the calculated power factor will be found to be higher than the true value. The reactance and impedance shall be determined at the temperature of the machine at the time of the test. Resistance values shall be corrected to the specified temperature before being reported as an equivalent circuit parameter.

The impedance data shall be determined from one of the following methods:

a) *Method 1*—A three-phase locked-rotor impedance test at maximum of 25% of rated frequency and at rated current. See 5.9.2 for details.

b) *Method 2*—Three-phase locked-rotor impedance tests at three frequencies; one at rated frequency, one at approximately 50% of rated frequency, and one at a maximum of 25% of rated frequency, all at rated current. Curves shall be developed from these three test points and used to determine the values of total reactance and rotor resistance at the required reduced frequency. See 5.9.3 for details.

c) *Method 3*—An impedance test at a slip speed approximating the desired reduced rotor frequency. In this method, the motor is run uncoupled or coupled to a reduced load, and the voltage is reduced to give approximately full load slip point.[7] The slip shall be measured carefully. See 5.9.4 for details.

d) *Method 4*—When none of the previous methods is practical, the following test may be utilized: a three-phase, locked-rotor impedance test at reduced voltage at rated frequency resulting in approximately rated current and a test under load. See 5.9.5 for details.

5.9.2 Calculation of parameters—Method 1

5.9.2.1 Locked rotor test

The rotor of a squirrel-cage motor is a symmetrical bar winding; therefore, the impedance of the motor is practically the same for any position of the rotor relative in the stator.

The impedance of a wound-rotor motor varies with the position of the rotor relative to the stator. It is therefore necessary when performing a locked-rotor impedance test to determine the rotor position that results in an average value of impedance. Before taking readings on wound-rotor machines, the rotor shall be short-circuited. The angular distance through which it is necessary to observe the current variation shall be determined by allowing the rotor to revolve slowly and observing the stator current, noting the distance the rotor must move for the stator current to complete a cycle. For machines having an integral number of slots per pole per phase in both rotor and stator, this distance will be equal to two-thirds of a pole pitch for three-phase machines. For machines having fractional slot windings, the angular distance may be as much as a full pole pitch.

The rotor of a wound-rotor motor shall be blocked so that it cannot rotate freely, but can be moved; and the impressed voltage shall be increased gradually until a current of approximately rated value is obtained. Voltage and current on all phases shall be read and recorded, and the voltage in the different phases shall be balanced. Holding the same voltage, the rotor shall be turned slowly and the minimum and maximum values of current during a complete cycle shall be recorded. The rotor shall then be blocked for the impedance test on the position that gives a current equal to the average of the minimum and maximum values previously recorded.

For the locked-rotor test, take simultaneous readings of voltage and current in all phases and of power input at several levels of voltage in order to establish the value with special care in the neighborhood of full-load current. The stator winding temperature or stator winding resistance shall also be recorded. Care shall be taken not to overheat the windings. Taking the highest readings first and the lower readings in succession will help to equalize the temperature.

5.9.2.2 Calculations

Plot curves using volts as abscissas and the amperes and the input power as ordinates. The curve of amperes vs. volts is usually a straight line, curving slightly upward at the higher values. On closed slot rotors, however, there is also a distinct curve upward at low voltage. Derive the value of voltage and power input to determine the total reactance and rotor resistance at the required level of current from these curves.

Determine the rotor resistance, R_2, and the total leakage reactance, $X_1 + X_2$, from these data using the Equation (27) through Equation (38). The calculations start by assuming a relationship between X_1 and X_2. When design details are available, use the calculated ratio X_1/X_2. Otherwise, use

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[7] This test is described herein as being run at a reduced voltage. This is because it is recognized that when using the more readily available small loading devices, a reduced voltage must be used to obtain the required full load slip test point. With suitable loading, this test may be performed at higher voltages; up to and including rated voltage.

$\left(\frac{X_1}{X_2}\right)$ = 1.0 for Design A, Design D, and wound rotor motors

$\left(\frac{X_1}{X_2}\right)$ = 0.67 for Design B motors

$\left(\frac{X_1}{X_2}\right)$ = 0.43 for Design C motors

NOTE—Design A, B, C, and D motors are defined in NEMA MG-1-2003 [B3].

Calculate the reactive power of complete motor at no load, Q_0, and at the conditions of the impedance test, Q_L.

$$Q_0 = \sqrt{(mV_{10}I_{10})^2 - P_0^2} \tag{27}$$

and

$$Q_L = \sqrt{(mV_{1L}I_{1L})^2 - P_L^2} \tag{28}$$

The per phase voltage, V_1, as used in Equation (27) and Equation (28) for a three phase machine is

$$V_1 = \frac{\text{Line-to-Line voltage}}{\sqrt{3}} \tag{29}$$

See Figure 2 for identification of the quantities and subscripts in the above and in the following equations.

Calculate the magnetizing reactance X_M.

$$X_M = \frac{mV_0^2}{Q_0 - (mI_{10}^2 X_1)} \times \frac{1}{\left(1 + \frac{X_1}{X_M}\right)^2} \tag{30}$$

Calculate the stator leakage reactance X_1 at test frequency.

$$X_{1L} = \frac{Q_L}{mI_{1L}^2 \times \left[1 + \left(\frac{X_1}{X_2}\right) + \frac{X_1}{X_M}\right]} \times \left[\left(\frac{X_1}{X_2}\right) + \frac{X_1}{X_M}\right] \tag{31}$$

Determine the stator leakage reactance at rated frequency.

$$X_1 = \frac{f}{f_L} \times X_{1L} \tag{32}$$

Equation (30), Equation (31), and Equation (32) may be solved as follows:

1) Solve Equation (30) for X_M, assuming a value of X_1/X_M and X_1
2) Solve Equation (31) for X_{1L}, using the same value of X_1/X_M as above

3) Solve Equation (32) for X_1
4) Solve Equation (30) for X_M, using X_1 from Equation (32) and a ratio of X_1/X_M from Equation (30) and Equation (32)
5) Continue iteration solution until stable values of X_1 and X_M are obtained within 0.1%

$$B_M = \frac{1}{X_M} \tag{33}$$

$$X_{2L} = \frac{X_{1L}}{\left(\frac{X_1}{X_2}\right)} \tag{34}$$

$$X_2 = \frac{f}{f_L} \times X_{2L} \tag{35}$$

$$G_{fc} = \frac{P_h}{mV_{10}^2} \times \left(1 + \frac{X_1}{X_M}\right)^2 \tag{36}$$

where

P_h is the total core loss, in W, as determined in 5.5.5.

$$R_{fe} = \frac{1}{G_{fe}} \tag{37}$$

$$R_{2L} = \left(\frac{P_L}{mI_{1L}^2} - R_{1L}\right) \times \left(1 + \frac{X_2}{X_M}\right)^2 - \left(\frac{X_2}{X_1}\right)^2 \times (X_{1L}^2 G_{fe}) \tag{38}$$

where

R_{1L} is equal to 1/2 of the line-to-line stator winding resistance, in ohms, at test temperature.

Correct R_{1L} and R_{2L} to the specified temperature using Equation (3) and identify as R_1 and R_2.

5.9.3 Calculation of parameters—Method 2

When using Method 2, perform the tests in 5.9.1 and use the calculation procedure in 5.9.2.2 to find the rotor resistance, R_{2L}, and total leakage reactance, $X_{1L} + X_{2L}$, at each of the three frequencies. Develop curves of the values of rotor resistance and total leakage reactance vs. frequency that can be used to determine the values at the required reduced operating frequency. The resulting value for rotor resistance and the values for leakage inductances, after conversion to operating frequency, are then used in the equivalent circuit to determine machine performance.

5.9.4 Calculation of parameters—Method 3

5.9.4.1 Reduced voltage slip test

The rotor resistance, R_2, and the leakage reactance, X_2, at reduced frequency may be obtained from readings (volts, watts, amperes, slip, stator winding temperature or stator winding resistance) at a slip speed approximating the desired reduced rotor frequency. In this method, the machine is run uncoupled or coupled to a reduced load and at a voltage that gives desired slip speed. A generator can be operated as a motor or to a reduced load and at a voltage that gives desired slip speed. A generator can be operated as a motor or can be coupled to driving equipment at a speed above synchronous speed that gives the desired slip while at a reduced voltage to reduce the electrical output. The slip shall be measured very carefully.

5.9.4.2 Calculations

With data from the no-load saturation test, see 5.5, calculate the total reactance per phase for each test point and draw a curve of total reactance per phase vs. no-load volts per phase. See example in Figure 3. The highest point on this curve is used as the total no-load reactance per phase, $X_1 + X_M$, in calculations of the reduced voltage slip test.

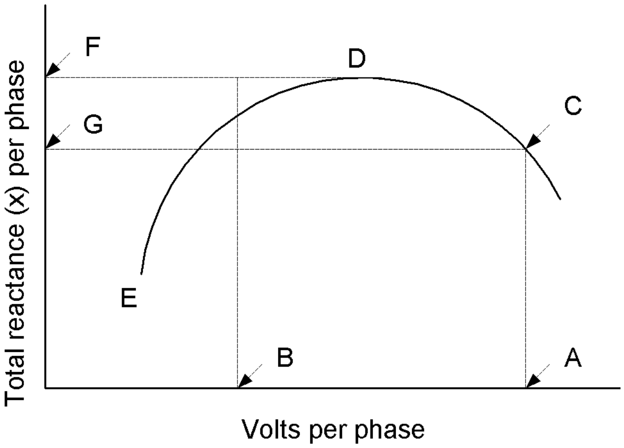

Figure 3—Total reactance from no load test

Quantities associated with Figure 3 are as follows:

A is rated volts.
B is volts at reduced voltage slip test.
CDE is curve of total reactance from no-load test.
F is reactance corresponding to the highest point, D, of the test curve CDE. This value is used as the total reactance, $X_1 + X_M$, in calculations of the reduced voltage slip test.
G is total reactance, $X_1 + X_M$, to be used in determining X_M for use in the equivalent circuit calculations after X_1, X_2, and R_2 are determined from the calculations of the reduced voltage test.

If the machine was operated as a motor in performing the reduced voltage slip test then the measured electrical power when used in the calculations should be specified as having a positive value. If the machine was tested as a generator, the measured electrical power used in the calculations is specified as having a negative value, since it is opposite in direction to the power flow as illustrated in Figure 2. From the reduced voltage slip test data, calculate the total impedance per phase, Z and the power factor, PF, (which will be negative for generator operation). The phase angle, θ_1, of the input current, the total apparent resistance per phase, R, and the total apparent reactance per phase, X, can be found as shown in Equation (39) through Equation (41):

$$\theta_1 = -\arccos(PF) \tag{39}$$

$$R = Z \times \cos(-\theta_1) \tag{40}$$

$$X = Z \times \sin(-\theta_1) \tag{41}$$

The value of X determined from Equation (41) is used as a first estimate for the sum $(X_1 + X_2)$. A value for the ratio (X_1/X_2) is obtained from design details, when known, or from 5.9.2.2. Based on this sum and ratio an initial estimate for the value of X_1 can be calculated as shown in Equation (42).

$$X_1 = X\frac{\left(\frac{X_1}{X_2}\right)}{1 + \left(\frac{X_1}{X_2}\right)} \tag{42}$$

Using the value of total no-load reactance, $(X_1 + X_M)$, from point D of Figure 3, the value of the magnetizing reactance, X_M, can be approximated as shown in Equation (43).

$$X_M = (X_1 + X_M) - X_1 \tag{43}$$

From the data obtained from the reduced voltage slip test, calculate

$$V_2 = \sqrt{[V_1 - I_1(R_1 \cos\theta_1 - X_1 \sin\theta_1)]^2 + [I_1(R_1 \sin\theta_1 + X_1 \cos\theta_1)]^2} \tag{44}$$

The resistance, R_1, shall be corrected to the temperature during the test before use in Equation (44) and in following equations.

When calculating the phase angle θ_2, the value is that for the quadrant associated with the signs of the values of the numerator and denominator terms in Equation (45).

$$\theta_2 = \arctan\frac{-I_1(R_1 \sin\theta_1 - X_1 \cos\theta_1)}{V_1 - I_1(R_1 \cos\theta_1 - X_1 \sin\theta_1)} \tag{45}$$

$$I_e = \frac{V_2}{X_M} \tag{46}$$

$$R_{fe} = \frac{V_2^2}{\left(\frac{P_h}{m}\right)} \tag{47}$$

$$G_{fe} = \frac{1}{R_{fe}} \tag{48}$$

$$I_{fe} = \frac{V_2}{R_{fe}} \tag{49}$$

Calculate

$$I_2 = \sqrt{[I_1 \cos\theta_1 - I_e \sin\theta_2 - I_{fe} \cos\theta_2]^2 + [-I_1 \sin\theta_1 + I_e \cos\theta_2 + I_{fe} \sin\theta_2]^2} \tag{50}$$

$$X_2 = \frac{-V_1 I_1 \sin\theta_1 - I_1^2 X_1 - I_e^2 X_M}{I_2^2} \tag{51}$$

$$X = X_1 + X_2 \tag{52}$$

Repeat Equation (42) through Equation (52) using the initial ratio of X_1 / X_2 as used in Equation (42) and the new value of X from Equation (52) and continue until stable values of X_1 and X_2 are achieved within 0.1%.

$$Z_2 = \frac{V_2}{I_2} \tag{53}$$

$$R_2 = s\sqrt{(Z_2^2 - X_2^2)} \tag{54}$$

Then, using the value of total reactance, $(X_1 + X_M)$, from the rated voltage no-load test point C in Figure 3, calculate

$$X_M = (X_1 + X_M) - X_1 \tag{55}$$

$$B_M = \frac{1}{X_M} \tag{56}$$

$$V_2 = \sqrt{[V_1 - I_1(R_1\cos\theta_1 + X_1\sin\theta_1)]^2 + [I_1(R_1\sin\theta_1 + X_1\cos\theta_1)]^2} \tag{57}$$

$$G_{fe} = \frac{P_h}{mV_2^2} \tag{58}$$

The values obtained in Equation (39), Equation (51), Equation (56), and Equation (58) are used in the equivalent circuit calculations. The rotor resistance, R_2, from Equation (54) and stator resistance, R_1, shall be corrected to the specified temperature using Equation (3) before being used in the equivalent circuit.

5.9.5 Calculation of parameters—Method 4

5.9.5.1 Locked-rotor and load point test

The following tests at rated frequency are required:

a) No-load test per 5.5.

b) Locked-rotor test at reduced voltage following the procedure in 5.9.2.1.

c) Operating the machine uncoupled (or coupled to some reduced load) with the voltage reduced to give approximately full-load slip. The slip must be determined very carefully.

For each test, record the volts, watts, amperes, slip, and stator winding resistance or stator winding temperature.

5.9.5.2 Calculations

The values of X_1, X_2, X_M, and R_{fe} are determined from the no-load and locked-rotor tests at rated frequency following the procedure in 5.9.2. The value of R_2 at reduced frequency is obtained from the test data recorded for operation at approximately full-load slip. The full-load slip is determined using nameplate speed or design data.

After X_1 has been determined from the locked-rotor impedance tests, see 5.9.2.2, the value of R_2 is obtained from the full-load slip test as follows:

— Calculate V_2 using Equation (44).

- Calculate θ_2 using Equation (45).
- Calculate I_{fe} and I_e using Equation (49) and Equation (46).
- Calculate I_2 using Equation (50).
- Calculate rotor impedance, Z_2 using Equation (53).

Calculate R_2 using Equation (54) and correct to the specified temperature using Equation (3).

5.10 Brush-contact loss

This measurement is used in efficiency methods F and F1 (see 6.8). For wound-rotor machines, the brush contact loss is determined by the product of the calculated secondary current and a voltage drop. The voltage drop in all brushes of the same phase (between rings on a three-ring machine) may be assumed to be 1.0 V for carbon or graphite brushes, and 0.3 V for metal-carbon brushes.

5.11 Power factor

5.11.1 Indirectly obtained

When determining the machine performance characteristics, the power factor of the machine shall be determined for each load point using Equation (59).

$$PF = \frac{P}{\sqrt{3} \times VI} \tag{59}$$

where

P is the machine electrical power, in W, input for a motor or output for a generator,
PF is the machine power factor,
V is input, line-to-line voltage, in volts,
I is input current, in A.

NOTE—The power factor, PF, obtained with Equation (59) is a numeric value, i.e., 0.xx. To obtain in percent form, multiply the numeric value by 100.

5.11.2 Directly obtained

When using the two-wattmeter method to measure input power of three-phase machines, the power factor, PF, in percent, may be checked by Equation (60).

$$PF = \frac{100}{\sqrt{1 + 3\left(\frac{P_1 - P_2}{P_1 + P_2}\right)^2}} \tag{60}$$

where

P_1 is the higher reading,
P_2 is the lower reading.

If the wattmeter for the P_2 reading gives a negative reading, it shall be considered a negative quantity.

If a polyphase wattmeter is used, the values of the two-wattmeter readings can be obtained by opening separately each of the voltage coil circuits of the polyphase wattmeter.

With pulsating loads, the power factor obtained by the direct method may be higher than that obtained by the indirect method. The higher value shall be taken as the correct reading. The difference is due to the inclusion in the volt-amperes of the pulsating component of current, which is a function of the load rather than of the machine itself. The power factor determined from the ratio of wattmeter readings is not affected by the presence of pulsating current.

5.11.3 Equivalent circuit calculation

The power factor, in percent, may be determined from the equivalent circuit by multiplying the total resistance by 100 and then dividing the result by the total impedance.

6. Determination of efficiency

6.1 General

Efficiency is the ratio of output power to total input power. Output power is equal to input power minus the losses. Therefore, if two of the three variables (output, input, or losses) are known, the efficiency can be determined by using Equation (61), Equation (62), or Equation (63).

$$\text{efficiency} = \frac{\text{output power}}{\text{input power}} \tag{61}$$

A form commonly used for motors is:

$$\text{efficiency} = \frac{\text{input power} - \text{losses}}{\text{input power}} \tag{62}$$

A form commonly used for generators is:

$$\text{efficiency} = \frac{\text{output power}}{\text{output power} + \text{losses}} \tag{63}$$

Unless otherwise specified, the efficiency shall be determined for rated voltage and frequency. When a load point is available at other than rated voltage, it may be combined with the equivalent circuit (Methods F and Fl) to calculate the performance at rated voltage (see 6.9).

6.2 Efficiency test methods

The various methods of efficiency and loss determination are identified as follows:

a)	*Method A*	Input-output
b)	*Method B*	Input-output with segregation of losses and indirect measurement of stray-load loss
c)	*Method B1*	Input-output with segregation of losses, indirect measurement of stray-load loss and an assumed temperature
d)	*Method C*	Duplicate machines with segregation of losses and indirect measurement of stray-load loss
e)	*Method E*	Electric power measurement under load with segregation of losses and direct measurement of stray-load loss

f) *Method E1* Electric power measurement under load with segregation of losses and assumed value of stray-load loss

g) *Method F* Equivalent circuit with direct measurement of stray-load loss

h) *Method F1* Equivalent circuit with assumed value of stray-load loss

i) *Method C/F* Equivalent circuit calibrated per Method C load point with indirect measurement of stray-load loss

j) *Method E/F* Equivalent circuit calibrated per Method E load point with direct measurement of stray-load loss

k) *Method E1/F1* Equivalent circuit calibrated per Method E load point with assumed value of stray-load loss

6.2.1 Guide for choice of efficiency test method

The input-output method (Efficiency Test Method A) should be limited to machines with ratings less than 1 kW.

Horizontal machines rated at 1–300 kW should be tested using Efficiency Test Method B, the input-output method with loss segregation.

Vertical machines in the range of 1–300 kW should be tested by Efficiency Test Method B if the machine bearing construction permits. If the bearing construction does not permit Method B testing, Method E, E1, F, or F1 may be used.

Machines rated higher than 300 kW should be tested by Efficiency Test Method B, B1, C, E, E1, F, or Fl depending on the capability of the test facility. When proper test facilities are available, Method B should be selected when the precision and repeatability of this method is required.

When practical, load test calibration of the equivalent circuit (Efficiency Test Method C/F, E/F, or E1/F1) provides the confidence level of a full-load test with the simplicity of determining performance at various loads by solution of the equivalent circuit.

6.3 Efficiency Test Method A—Input-output

For this method, the efficiency is calculated as the ratio of the measured output power to the measured input power, after temperature and dynamometer corrections, if applicable.

6.3.1 Test procedure

6.3.1.1 Cold resistance

With the machine at ambient temperature, measure and record the winding(s) resistances and the ambient temperature. See 5.4.

6.3.1.2 Rated load temperature test

Perform a rated load temperature test in accordance with 5.8.3.1.

6.3.1.3 Test under load

The machine is loaded by means of a mechanical brake or dynamometer. See 5.6.1.

6.3.1.4 Calculations

Performance is calculated as shown in Form A in 9.2 with details of the calculations shown in Form A2 in 9.3. Dynamometer correction should be made, if applicable, as shown in 5.6.1.2. The stator I^2R loss and the slip are to be corrected for temperature as indicated.

6.3.1.5 Temperature correction

The stator power is corrected to the specified temperature. The amount of power correction required is determined by Equation (64).

$$P_c = I_t^2 R_s - I_t^2 R_t \tag{64}$$

where

P_c is the necessary power correction, in W,
I_t is the line current, in A, during the test,
R_t is the average winding resistance, in ohms, at shutdown,
R_s is R_t corrected to the specified temperature, see Equation (3).

The corrected stator power for a motor is the measured electrical power during the test plus P_c. The corrected stator power for a generator is the measured electrical power during the test minus P_c.

The measured slip is corrected to the specified temperature using Equation (9) in 5.3.2.

6.3.2 Efficiency

Use the corrected electrical and the mechanical power values to calculate efficiencies. See 6.1.

6.4 Efficiency Test Method B—Input-output with loss segregation

All data are taken with the machine operating either as a motor or as a generator, depending upon the region of operation for which the efficiency data are required. The apparent total loss (input minus output) is segregated into its various components with stray-load loss defined as the difference between the apparent total loss and the sum of the conventional losses (stator and rotor I^2R loss, core loss, and friction and windage loss). The value of stray-load loss thus determined is plotted vs. torque squared, and a linear regression is used to reduce the effect of random errors in the test measurements. The smoothed stray-load loss data are used to calculate the final value of total loss and the efficiency.

6.4.1 Test procedure

The individual tests that make up the Method B test method shall be performed in the order listed. It is not necessary that these tests be performed in time succession with each immediately following the previous one. The tests may be performed individually if the operating temperature of the machine is established close to its normal operating temperature for the type of test prior to obtaining the test data.

6.4.1.1 Cold resistance

With the machine at ambient temperature, measure and record the winding(s) resistances and the ambient temperature. See 5.4.

6.4.1.2 Rated load temperature test

A rated load temperature test, using a dynamometer, is to be performed in accordance with 5.8.3.1. This test is not required when a rated load temperature test had previously been performed on a duplicate machine. Determine the specified temperature for the machine. See 3.3.2 a) or b).

6.4.1.3 Test under load

During this test, the machine shall be loaded by a dynamometer, see 5.6.1. The temperature of the stator winding shall be within 10 °C of the hottest temperature reading recorded during the rated load temperature test on this or the duplicate machine prior to the start of recording data for this test. Perform the test as quickly as possible to minimize temperature changes in the machine during testing. When necessary, a dynamometer correction test shall be made. See 5.6.1.2.

6.4.1.4 No-load test

Perform a no-load test in accordance with 5.5 and 5.5.1.

6.4.2 Calculations

6.4.2.1 Calculation form

Calculate motor or generator performance using Form B in 9.4 as a guide. The source of each of the items on Form B or the method of its calculation is shown on Form B2 in 9.5.

6.4.2.2 Friction and windage loss

See 5.5.4.

6.4.2.3 Core loss

See 5.5.5.

6.4.2.4 Stator I^2R loss

See 5.2.

This calculation of stator I^2R losses for each load point shall be accomplished using the average winding resistance. If the average winding resistance is measured at each point during the load test, it can be directly used in the determination of the stator I^2R loss at that load point. If the winding temperature is obtained by means of local or embedded detectors, these readings shall be converted into an equivalent average value before performing the loss calculations.

From the rated load temperature test of 6.4.1.2, obtain the winding resistance at shutdown and the temperature at shutdown by both the winding resistance and by local detector. This should be the same local detector being used during the load test. A value closely approximating the average temperature can then be determined by Equation (65).

$$t_A = \frac{t_{TR} t_t}{t_{TTD}} \tag{65}$$

where

t_A is the developed average temperature, in °C, for use in the loss calculations,

t_{TR} is the total temperature, in °C, from the shut down of the temperature test,

t_t is the temperature, in °C, by detector during the load test,

t_{TTD} is the temperature, in °C, by detector from the shutdown of the temperature test.

The average resistance to be used for the stator I^2R loss can be determined by Equation (3) using $t_{TR} = t_a$, $t_A = t_b$ and R_a equal to the resistance value at temperature test shutdown. This calculation procedure is repeated for each load point.

6.4.2.5 Rotor I^2R loss

See 5.3. The first calculation of rotor I^2R loss is based on actual speed or slip measurement for each point and no adjustments are required.

6.4.2.6 Apparent total loss

The apparent total loss shall be calculated separately for each load point by subtracting the measured output in watts from the measured input in watts.

6.4.2.7 Stray-load loss determination (indirect method)

The stray-load loss shall be separately calculated for each load point by subtracting from the apparent total loss the stator I^2R loss at the temperature of the test, the core loss, the friction and windage loss, and the rotor I^2R loss corresponding to the measured value of slip.

6.4.2.8 Smoothing of the stray-load loss

Smooth the stray-load loss data by using a linear regression analysis based on expressing the stray-load loss as a function of the square of the load torque. The results of the analysis should be as shown in Equation (66).

$$P_{SL} = AT^2 + B \tag{66}$$

where

P_{SL} is the stray-load loss, in W, as plotted vs. torque squared,

T is the torque, in N·m,

A is the slope,

B is the intercept with the zero torque line.

If the slope is negative, or if the correlation factor is less than 0.9, delete the worst point and repeat the regression analysis. If this increases the correlation factor to 0.9 or larger, use the second regression; if not, or if the slope is still negative, the test is unsatisfactory. Errors in the instrumentation or test readings, or both, are indicated. The source of the error should be investigated and corrected, and the test under load, see 6.4.1.3, should be repeated.

6.4.3 Corrections

6.4.3.1 Corrected stray-load loss

The stray-load loss curve of 6.4.2.8 is corrected by shifting the curve to go through the origin while maintaining the original slope. The result of this correction is Equation (67), which is used to determine the corrected value of stray-load loss, P_{SLc}, for each load point.

$$P_{SLc} = AT^2 \tag{67}$$

where

A is the slope of the of the P_{SL} vs. T^2 curve defined in 6.4.2.8,
T is the torque, in N·m, for each load point as used in 6.4.2.8.

6.4.3.2 Temperature correction of stator I^2R loss

A corrected stator I^2R loss for each of the load points is calculated using the average stator resistance corrected to the specified temperature. Using resistance and the total temperature, by resistance, at shutdown from 6.4.1.2, correct this resistance to the specified temperature using Equation (3). Calculate the loss as in 5.2.

6.4.3.3 Temperature correction of rotor I^2R loss

A corrected rotor I^2R loss for each of the load points is calculated as in 5.3, Equation (4) or Equation (5), using the value of slip for each of the points corrected to the specified temperature, using Equation (9), and using the corrected value of the stator I^2R loss, from 6.4.3.2, for each load point. The slip used in Equation (4) or Equation (5), is the slip used in 6.4.2.5 corrected to the specified temperature from the developed average temperature from 6.4.2.4.

6.4.3.4 Corrected total loss

A corrected total loss for each of the load points is determined as the sum of the friction and windage loss (see 6.4.2.2), the core loss (see 6.4.2.3), the corrected stray-load loss (see 6.4.3.1), the corrected stator I^2R loss (see 6.4.3.2), and the corrected rotor I^2R loss (see 6.4.3.3).

6.4.3.5 Corrected mechanical power

The corrected mechanical (output) power for each of the load points for a motor is equal to the difference between the measured electrical (input) power and the corrected total loss. The corrected mechanical (input) power for a generator is equal to the sum of the measured electrical (output) power and the corrected total loss.

6.4.4 Efficiency

Use the measured electrical power and the corrected mechanical power to calculate efficiency. See 6.1.

6.4.5 Power factor

The power factor of the machine shall be determined for each load point using Equation (59). See 5.11.

6.4.6 Summary of characteristics

The summary of characteristics is a listing of the power factor, the efficiency, the speed, and the line current at precise load points. To obtain this information, plot the values from the analysis for the line current, speed, and efficiency vs. the output power. Fit curves to these data and pick off the values for the desired load points. The power factor is computed for each precise load point from its amperes, volts, and input watts as in Equation (59).

This summary of machine characteristics is included in Form B. See 9.4.

6.5 Efficiency Test Method B1—Input-output with loss segregation and assumed temperature

All data are taken with the machine operating either as a motor or as a generator, depending upon the region of operation for which the efficiency data are required. The apparent total loss (input minus output) is segregated into its various components with stray-load loss defined as the difference between the apparent total loss and the sum of the conventional losses (stator and rotor I^2R loss, core loss, and friction and windage loss). The value of stray-load loss thus determined is plotted vs. torque squared, and a linear regression is used to reduce the effect of random errors in the test measurements. The smoothed stray-load loss data are used to calculate the final value of total loss and the efficiency.

6.5.1 Test procedure

The individual tests that make up the Method B1 test method shall be performed in the order listed. It is not necessary that these tests be performed in time succession with each immediately following the previous one. The tests may be performed individually if the operating temperature of the motor is established close to its normal operating temperature for the type of test prior to obtaining the test data.

6.5.1.1 Cold resistance

With the machine at ambient temperature, measure and record the winding(s) resistances and the ambient temperature. See 5.4.

6.5.1.2 Temperature

A load test to determine temperature rise and total temperature is not performed in Efficiency Test Method B1. The specified temperature is determined as in 3.3.2 c).

6.5.1.3 No-load test

Perform a no-load test in accordance with 5.5 including the bearing loss stabilization step of 5.5.1.

6.5.1.4 Test under load

For this test, the machine shall be loaded by a dynamometer, see 5.6.1. The temperature of the stator winding shall be within 10 °C of the specified temperature, as selected in 6.5.1.2, prior to the start of recording data for this test. Perform the test as quickly as possible to minimize temperature changes in the machine during testing. When necessary, a dynamometer correction test shall be made. See 5.6.1.2.

6.5.2 Calculations

6.5.2.1 Calculation form

Calculate motor or generator performance using Form B1 in 9.6 as a guide. The source of each of the items on Form B1 or the method of its calculation is shown on Form B1-2 in 9.7.

6.5.2.2 Friction and windage loss

See 5.5.4.

6.5.2.3 Core loss

See 5.5.5.

6.5.2.4 Stator I^2R loss

See 5.2. Calculate loss with winding resistance corrected to the test temperature.

6.5.2.5 Rotor I^2R loss

See 5.3. This first calculation of rotor I^2R loss is based on actual speed or slip measurement for each point and no adjustments are required.

6.5.2.6 Apparent total loss

The apparent total loss shall be calculated separately for each load point by subtracting the measured output in watts from the measured input in watts.

6.5.2.7 Stray-load loss determination (indirect method)

6.5.2.8 Smoothing of the stray-load loss

The stray-load loss shall be separately calculated for each load point by subtracting from the apparent total loss the stator I^2R loss at the temperature of the test, the core loss, the friction and windage loss, and the rotor I^2R loss corresponding to the measured value of slip.

Smooth the stray-load loss data by using a linear regression analysis based on expressing the stray-load loss as a function of the square of the load torque. The results of the analysis should be as shown in Equation (66) in 6.4.2.8.

If this analysis shows the slope as negative, or if the correlation factor is less than 0.9, delete the worst point and repeat the regression analysis. If this increases the correlation factor to 0.9 or larger, use the second regression; if not, or if the slope is still negative, the test is unsatisfactory. Errors in the instrumentation or test readings, or both, are indicated. The source of the error should be investigated and corrected, and the test under load, see 6.5.1.4, should be repeated.

6.5.3 Corrections

6.5.3.1 Corrected stray-load loss

The corrected value of stray-load loss, P_{SLc} is determined using Equation (67) with T equal to the torque for each of the load points and A is the slope of the function curve as determined in 6.5.2.8.

6.5.3.2 Temperature correction of stator I^2R loss

A corrected stator I^2R loss for each of the load points is calculated using the average cold stator resistance from 6.5.1.1 corrected to the specified temperature. Calculate the loss as in 5.2.

6.5.3.3 Temperature correction of rotor I^2R loss

A corrected rotor I^2R loss for each of the load points is calculated as in 5.3, Equation (4) or Equation (5), using the value of slip for each of the points corrected to the specified temperature, using Equation (9), and using the corrected value of the stator I^2R loss, from 6.5.3.2, for each load point. The slip used in Equation (4) or Equation (5), is the slip used in 6.5.2.5 corrected to the specified temperature from the test temperature at the applicable test point.

6.5.3.4 Corrected total loss

A corrected total loss for each of the load points is determined as the sum of the friction and windage loss (see 6.5.2.2), the core loss (see 6.5.2.3), the corrected stray-load loss (see 6.5.3.1), the corrected stator I^2R loss (see 6.5.3.2), and the corrected rotor I^2R loss (see 6.5.3.3).

6.5.3.5 Corrected mechanical power

The corrected mechanical (output) power for each of the load points for a motor is equal to the difference of the measured electrical (input) power and the corrected total loss. The corrected mechanical (input) power for a generator is equal to the sum of the measured electrical (output) power and the corrected total loss.

6.5.4 Efficiency

Use the measured electrical power and the corrected mechanical power to calculate efficiency. See 6.1.

6.5.5 Power factor

The power factor of the machine shall be determined for each load point using Equation (59) of 5.11.

6.5.6 Summary of characteristics

The summary of characteristics is a listing of the power factor, the efficiency, the speed, and the line current at precise load points. To obtain this information, plot the values from the analysis for the line current, speed, and efficiency vs. the output power. Fit curves to these data and pick off the values for the desired load points. The power factor is computed for each precise load point from its amperes, volts, and input watts as in Equation (59).

This summary of machine characteristics is included in Form B1. See 9.6.

6.6 Efficiency Test Method C–Duplicate machines

This method of determining efficiency may be used when duplicate machines are available. The two machines are coupled together and electrically connected to two sources of power, the frequency of one being adjustable. Both power supplies must meet the requirements of 3.1.2 and 3.1.3 and must be capable of power delivery and power absorption. The stray-load loss is determined by the indirect method.

6.6.1 Test procedure

The individual tests that make up the Method C efficiency test shall be performed in the order listed. It is not necessary that these tests be performed in time succession with each immediately following the previous one. The tests may be performed individually if the operating temperatures of the machines are established close to their normal operating temperature for the type of test prior to obtaining the test data.

For convenience in this analysis description, the machine connected to the constant rated frequency power supply during the load test is identified as machine M1 and the machine connected to the variable voltage, variable frequency supply is identified as machine M2.

6.6.1.1 Cold resistance

With the machines at ambient temperature, measure and record the winding(s) resistances of both machines and the ambient temperature. See 5.4.

6.6.1.2 No-load tests of both machines

Perform no-load tests on both machines. See 5.5.

6.6.1.3 Test under load

Couple the two machines together and arrange for machine M1 to be supplied from the rated frequency power supply and for machine M2 to operate from the variable power supply. Machine M1 shall be loaded as a motor and as a generator at line currents corresponding to four load points approximately equally spaced between not less than 25% and up to and including 100% load, and two load points suitably chosen above 100% load but not exceeding 150% load. More load points may be used if desired. At each test point, obtain readings of electrical power, current, voltage, frequency, and stator winding temperature or stator winding resistance for both machines, along with speed and ambient temperature.

The test should start at the highest load point with machine M1 operating as a motor. While maintaining rated voltage and frequency on machine M1, decrease the frequency and voltage on machine M2 until the line current for machine M1 is approximately equal to that at the highest load point. When the voltage on machine M2 divided by the frequency of that voltage is equal to the rated voltage divided by rated frequency, this is a valid test point and the readings above should be obtained.

Directly after obtaining the above readings, increase the frequency and voltage on machine M2 above rated frequency until the current on machine M1, now operating as a generator, is the same as that recorded when machine M1 was operating as a motor. When the machine M2 voltage/frequency value is correct, this is a valid test point and the readings above should be obtained.

The two sets of readings, with machine M1 operating as a motor and as a generator, complete the test data required for that load point. Then the test can proceed to the next test point and the data set with machine M1 acting as generator can be collected first.

Continue in this manner takings readings for both directions of power flow until the sets of test data for all desired load points have been recorded. Perform this test as quickly as possible to minimize temperature changes in the machines during testing.

When performing the first portion of the test at any load point, it is not necessary that the current be adjusted to precisely the predetermined current value; however, the current during the second portion of the test at that load point shall match that of the first as closely as the test equipment will permit.

6.6.2 Calculations

6.6.2.1 Calculation form

Calculate the machine performance using Form C in 9.8 as a guide. Form C2 in 9.9 is provided to assist in understanding each item in the test and in the calculations. Take care in the organization of the data. The analysis requires the use of information and data from both machines in the calculations for both portions of each load point. Form C is arranged to present all these data in the proper sequence.

6.6.2.2 Friction and windage

See 5.5.4.

6.6.2.3 Core loss

See 5.5.5.

6.6.2.4 Stator I^2R loss

See 5.2.

The measured test temperature shall be used when adjusting the winding resistance for this loss determination. The procedure for temperature refinement presented in 6.4.2.4 may be used if desired but only when a full load temperature test has been performed on one of the machines. Two calculations for each machine are required for each load point, one during its motoring operation and the other during its generating operation.

6.6.2.5 Rotor I^2R loss

See 5.3. This calculation is based on the actual speed or slip measurement for each portion of each point and no adjustments are required. Two calculations for each machine are required for each load point. Take care that the proper power flow is observed. Using the description of a load point test in 6.6.1.3, machine M1 is a motor and Equation (68) should be used while machine M2 is a generator and Equation (69) applies. For the second half of each point, this switches with Equation (69) being applied to machine M1 calculations and Equation (68) to machine M2 calculations.

The motor rotor I^2R loss is:

$$\text{motor rotor } I^2R \text{ loss} = \text{motor slip} \times (\text{motor input} - \text{stator } I^2R \text{ loss} - \text{core loss}) \tag{68}$$

Where the last quantity, motor input – stator I^2R loss – core loss, is the power across the air gap of the motor and the motor slip, in p.u., is the observed slip or calculated from measured speed and frequency.

The generator rotor I^2R loss is:

$$\text{generator rotor } I^2R \text{ loss} = \text{generator slip} \times (\text{generator output} + \text{stator } I^2R \text{ loss} + \text{core loss}) \tag{69}$$

Where the last quantity, generator output + stator I^2R loss + core loss, is the power across the air gap of the generator and the generator slip, in p.u., is the observed slip or is as calculated from measured speed and frequency.

6.6.2.6 Stray-load loss

6.6.2.6.1 Machine M1 operating as a motor

The combined stray-load loss is determined by subtracting from the total measured loss (the difference between input and output) the sum of the stator I^2R losses, rotor I^2R losses, core losses, and friction and windage losses of the two machines.

The stray-load losses are assumed to be proportional to the square of the rotor current. The stray-load losses are as shown in Equation (70) and Equation (71).

For machine M1 (as a motor):

$$\text{motor stray-load loss} = \text{motor rotor } I^2R \text{ loss} \times \frac{\text{combined stray-load loss}}{\text{motor rotor } I^2R + \text{generator rotor } I^2R \text{ loss}} \tag{70}$$

For machine M2 (as a generator):

$$\text{generator load loss} = (\text{combined stray load loss}) - (\text{motor stray load loss}) \tag{71}$$

6.6.2.6.2 Machine M1 operating as a generator

Repeat the calculations of 6.4.2.4 through 6.4.2.6 with the reversed power flow. Machine M2 is now the motor and its stray-load loss is determined using Equation (70). Machine M1 is now the generator and its stray-load loss is determined using Equation (71).

6.6.2.6.3 Averaging

The preliminary value of the stray-load loss of machine M1 is the average of the two values determined for that machine in 6.6.2.6.1 and 6.6.2.6.2. The preliminary value of the stray-load loss of machine M2 is the average of the two values determined for that machine in 6.6.2.6.1 and 6.6.2.6.2.

The average of these two preliminary values shall be considered the stray-load loss for use in the smoothing process described in 6.6.2.7.

6.6.2.7 Smoothing of the stray-load loss

Smooth the stray-load loss data from 6.6.2.6.3 by using a linear regression analysis based on expressing the stray-load loss as a function of the square of the rotor current. The results of the analysis should be as shown in Equation (72).

$$P_{SLavg} = A(I_{2avg})^2 + B \tag{72}$$

where

P_{SLavg} is the average value of stray-load loss, in W, as plotted vs. approximate rotor current squared,
A is the slope,
B is the intercept with the zero current line,
I_{2avg} is the average value of rotor current, in amperes.

The value of rotor current, I_2, for each direction of power flow (motoring and generating) is as shown in Equation (73).

$$I_2 = \sqrt{(I^2 - I_0^2)} \tag{73}$$

where

I is the observed value of stator line current, in amperes, (motoring or generating) for which stray-load loss is to be determined,

I_0 is the value of no-load current, in amperes.

If this analysis shows the slope as negative, or if the correlation factor is less than 0.9, delete the worst point and repeat the regression analysis. If this increases the correlation factor to 0.9 or larger, use the second regression; if not, or if the slope is still negative, the test is unsatisfactory. Errors in the instrumentation or test readings, or both, are indicated. The source of the error should be investigated and corrected, and the test under load, see 6.6.1.3, should be repeated.

6.6.3 Corrections

The correction on stray-load loss could be applied to either machine; however, the corrections of other losses are performed on machine M1. The performance of machine M2 could be determined in a similar manner if desired.

6.6.3.1 Corrected stray-load loss

The corrected value of stray-load loss is as shown in Equation (74).

$$P_{SLc} = A(I_2)^2 \tag{74}$$

where

A is the slope of the of the P_{SL} vs. I^2 curve defined in 6.6.2.7,

I_2 is the rotor current, in amperes, for each load point as used in 6.6.2.7.

6.6.3.2 Temperature correction of stator I^2R loss

A corrected stator I^2R loss for each of the load points is calculated using the average stator resistance corrected to the specified temperature. If a full load temperature test was performed, use the total temperature, by resistance, at shutdown and correct the resistance taken at shutdown to the specified temperature using Equation (3). When no temperature test is performed, correct the cold resistance in 6.6.1.1 to the specified temperature of 3.3.2 b) or 3.3.2 c), as applicable. Calculate the loss as in 5.2.

6.6.3.3 Temperature correction of rotor I^2R loss

A corrected rotor I^2R loss for each of the load points is calculated as in 5.3, Equation (4), using the value of slip for each of the points corrected to the specified temperature, using Equation (9), and using the corrected value of the stator I^2R loss, from 6.6.3.2, for each load point. The slip used in Equation (4) or Equation (5), is the slip used in 6.6.2.5 corrected to the specified temperature.

6.6.3.4 Corrected total loss

A corrected total loss for each of the load points is determined as the sum of the friction and windage loss (see 6.6.2.2), the core loss (see 6.6.2.3), the corrected stray-load loss (see 6.6.3.1), the corrected stator I^2R loss (see 6.6.3.2), and the corrected rotor I^2R loss (see 6.6.3.3).

6.6.3.5 Corrected mechanical power

The corrected mechanical (output) power for each of the load points for a motor is equal to the difference of the measured electrical (input) power and the corrected total loss. The corrected mechanical (input) power for a generator is equal to the sum of the measured electrical (output) power and the corrected total loss.

6.6.4 Efficiency

Use the measured electrical power and the corrected mechanical power to calculate efficiency. See 6.1.

6.6.5 Power factor

The power factor of the machine shall be determined for each load point using Equation (59). See 5.11.

6.6.6 Summary of characteristics

The summary of characteristics is a listing of the power factor, the efficiency, the speed and the line current at precise load points. To obtain this information, plot the values from the analysis for the line current, speed, and efficiency vs. the output power. Fit curves to these data and pick the values off for the desired load points. The power factor is computed for each precise load point from its amperes, volts, and input watts as in Equation (59).

This summary of machine characteristics is included in Form C. See 9.8.

6.7 Efficiency Test Method E or E1—Electrical power measurement with loss segregation

This test method measures the input power and determines the output power by subtracting the total losses from the input. The total losses are equal to the sum of stator and rotor losses corrected to the specified temperature for resistance correction, core loss, friction and windage loss, and stray-load loss.

6.7.1 Test procedure

6.7.1.1 Cold resistance

With the machine at ambient temperature, measure and record the winding(s) resistances and the ambient temperature.

6.7.1.2 Test under load

To obtain the required data, it is necessary to couple, belt, or gear the machine to a variable load and test per 5.6.2.

6.7.1.3 No-load test

Perform a no-load test in accordance with 5.5.

6.7.1.4 Stray-load test

The value of stray-load loss at full load for use with Efficiency Test Method E is determined by the direct method. Perform the test per 5.7.2 or 5.7.3. Efficiency Test Method E1 uses an assumed value from 5.7.4 and no test is required.

6.7.2 Calculations

6.7.2.1 Calculation form

Calculate motor or generator performance using Form E in 9.10 as a guide. The source of each of the items on Form E or the method of its calculation is shown on Form E2 in 9.11.

6.7.2.2 Windage and friction loss

See 5.5.4.

6.7.2.3 Core loss

See 5.5.5.

6.7.2.4 Stator I^2R loss

See 5.2.

The stator I^2R loss shall be corrected to the specified winding temperature. The stator winding resistance for each load point can be estimated by comparing the temperature rise measured by an embedded temperature detector, a temperature sensor located on the stator coil end, or the air outlet temperature rise, with corresponding temperature rise measurements obtained as steady-state values during a temperature test. When no temperature test is performed, the comparison is made with the total temperature assumed for the test.

6.7.2.5 Rotor I^2R loss

See 5.3.

The slip value shall be corrected to the specified winding temperature before performing this calculation.

6.7.2.6 Stray-load loss

With the full load stray-load loss established by the test in 6.7.1.4, the loss level for each of the load points is determined by a ratio of the square of the rotor currents. See Equation (22). The rotor currents used at each of these points is calculated using Equation (23).

6.7.2.7 Total losses and output power

The total losses of the machine are the sum of the windage and friction losses, the core loss, the stator I^2R loss, the rotor I^2R loss, and the stray-load loss.

The output power at the shaft for a motor is equal to the electrical input to the stator minus the above total losses.

For a generator, the output power is equal to the electrical input power during the load test and the input power at the shaft is equal to the test electrical power input power plus the above losses.

6.7.3 Motor/generator performance

The efficiency for each test point is calculated using the input and output values of 6.7.2.7. The values of efficiency, line current, and speed may be plotted against load and values at specific load levels may be selected for the machine performance report. The power factor for each of these specific loads is calculated as in 5.11.

6.8 Efficiency Test Method F or F1—Equivalent circuit

When tests under load are not made, operating characteristics are calculated based upon the equivalent circuit shown in Figure 2. The machine parameters in the equivalent circuit are derived from test data recorded during a no-load test and an impedance test. Accurate prediction of machine characteristics in the normal operating range will depend primarily upon the closeness by which R_2 represents the actual rotor resistance to currents of low frequency and, secondarily, upon the closeness by which X_2 represents the actual rotor leakage reactance to currents of low frequency. Therefore, the most careful procedure during testing to determine the rotor characteristics at low frequency is imperative.

6.8.1 Test procedure

6.8.1.1 Cold resistance

With the machine at ambient temperature, measure and record the winding(s) resistances and the ambient temperature.

6.8.1.2 No-load test

Perform a no-load test in accordance with 5.5. Prior to making this test, the machine shall be operated at no-load until the input power has stabilized. See 5.5.1.

6.8.1.3 Impedance test

See 5.9.1.

6.8.1.4 Friction and windage loss

See 5.5.4.

6.8.1.5 Core loss

See 5.5.5.

6.8.1.6 Determine equivalent circuit

Determine the value of all parameters of the equivalent circuit. See 5.9.

6.8.1.7 Stray-load loss

6.8.1.7.1 Test Method F

See 5.7.2 or 5.7.3.

6.8.1.7.2 Test Method F1

See 5.7.4.

6.8.2 Calculation form

The calculations start with the assumptions of slip values for each calculation point and proceed through steps shown in Form F2, 9.13. After completion of the first series of calculations, the results shall be reviewed and new slip values selected that may more clearly represent the desired load points. Repeat the calculations to complete the summary of characteristics. Iterative calculations can be used to determine the proper slip values. Forms F and F2 (see 9.12 and 9.13) are used for the performance calculations. The forms are arranged on the basis of X_1 and X_2 remaining constant throughout the range of operation of the machine. Should the curve of locked-rotor current vs. voltage depart from a straight line in the range of currents under consideration in the test per 5.9.1, each column of calculations in 9.12 shall use values of reactance obtained from this curve for the value of I_1 calculated in the column.

6.8.3 Calculation of maximum torque

Maximum or breakdown torque in a motor can be approximated from the calculation procedure in 9.13 using the slip value shown in Equation (75).

$$s = \frac{R_2}{\sqrt{R_1^2 + (X_1 + X_2)^2}} \tag{75}$$

See Figure 2 for explanation of symbols.

6.9 Efficiency Test Method C/F, E/F, or E1/F1—Equivalent circuit calibrated with one load point

When a test point under load at a stator temperature of t_t is available, the equivalent circuit derived in 6.8 can be calibrated by finding improved values for R_2 and X_M. The following procedure is used after initial values for the equivalent circuits parameters in 9.14 have been determined:

a) Use Forms F and F2 (see 9.12 and 9.13), but start with the second line with an assumed value of R_2/s for the test load point and the value of R_1 based on stator winding temperature of t_t. After reaching the calculation of stator power, check calculated value of input current and input power vs. measured values of input current and input power.

b) Adjust R_2/s and X_M and iterate until the calculated value of input power and input current both agree with the measured value of input current and input power within 1%. Other circuit parameters should not be adjusted. (Input power is primarily a function of R_2/s.)

c) Obtain R_2 by multiplying the final assumed value of R_2/s by the measured value of slip in per unit of synchronous speed. This procedure establishes the value of R_2 (without temperature correction) to be used in calculating the load performance characteristics.

d) Correct R_1 and R_2 to the specified temperature, t_s, using Equation (3), and determine performance at desired load points following the format shown in 9.12.

6.9.1 Stray-load loss

6.9.1.1 Test Method C/F

For Method C/F, the stray-load loss shall be determined as follows:

a) For both the motoring and generating load points, determine the average value of stray-load loss, P_{SLavg}, following the procedure in 6.6.2.6.

b) Determine the average value of rotor current for both the motoring and generating load points using Equation (73) for both calculations. The average of these two values is I_{2avg} for use in Equation (76).

c) The value of stray-load loss, P_{SL}, for any load point is then calculated as shown in Equation (76).

$$P_{SL} = P_{SLavg}\left(\frac{I_2}{I_{2avg}}\right)^2 \tag{76}$$

where

P_{SLavg} is the average value of stray-load loss from step a),
I_2 is the rotor current, in A, determined by solution of the equivalent circuit for the appropriate load point,
I_{2avg} is the average value of rotor current, in A, from step b).

The value of stray-load loss, P'_{SL}, reported in 9.13 should correspond to a value of I_{2avg} equal to the average value of rotor current as determined from step b).

6.9.1.2 Test Method E/F

See 5.7.2 or 5.7.3.

6.9.1.3 Test Method E1/F1

See 5.7.4.

6.9.2 Calculations form

See 9.12 and 9.13.

7. Other performance tests

7.1 Rotor voltage

On wound-rotor machines, the voltages shall be measured between all rotor terminals, with the rotor locked and its windings open-circuited and with rated voltage being applied to the stator. If any unbalance is detected, it is usual practice to take readings with several rotor positions to determine an average.

7.2 Locked-rotor tests

7.2.1 Current

This test may be performed either to check for quality or to determine performance. When possible, readings shall be taken at rated voltage and frequency since the current is not directly proportional to the voltage because of changes in reactance caused by saturation of the leakage paths. When the test is made to check the quality of squirrel-cage machines, it is possible to omit the mechanical means of locking the rotor by applying single-phase power of rated voltage and frequency to any two of the machine line terminals of a three-phase machine. With a three-phase machine, the line current will be approximately 86% and the power input will be approximately 50% of the corresponding values obtained with polyphase power. The values so obtained may be compared with those measured on a duplicate unit that has been subjected to a complete test.

7.2.2 Torque

The locked-rotor torque is taken as the minimum torque developed at rest in all angular positions of the rotor. The torque may be measured with a scale or force transducer with a rope and pulley, or with a brake or beam or it may be measured directly using an in-line torque transducer. Wound-rotor motors are always subject to variations in locked-rotor torque, depending on the angular position of the rotor with respect to the stator. For squirrel-cage motors, it is usual practice to lock the rotor in any convenient position. If the locked-rotor torque is not measured directly as mentioned above, the approximate locked-rotor torque may be calculated as shown in Equation (77).

$$T = \frac{C_1 k_2 (P_{si} - P_{SIR} - P_h)}{n_s} \tag{77}$$

where

T is torque, in N·m,
P_{si} is the input power to stator, in W,
P_{SIR} is the stator I^2R loss, in W, at the test current (see 5.2),
P_h is the core loss, in W, at test voltage (see 5.5.5),
n_s is the synchronous speed, in r/min,
C_1 is a reduction factor to account for nonfundamental losses,
k_2 is 9.549 for torque in N·m.

NOTE—C_1 can be any value between 0.9 and 1.0. Unless there is past experience to guide the tester, a value of .91 is suggested.

7.2.3 Power

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

7.3 Tests for speed-torque and speed-current curves

7.3.1 Definitions

7.3.1.1 Speed-torque characteristic

The speed-torque characteristic is the relationship between torque and speed, embracing the range from zero to synchronous speed for a motor and from synchronous speed to pull-out speed for an induction generator. This relation, when expressed as a curve, will include maximum (breakdown), pull up or pull out, and locked-rotor torques.

For wound-rotor motors, the torque and current shall be measured between synchronous speed and the speed at which maximum torque occurs. The slip rings shall be short-circuited for this test.

7.3.1.2 Speed-current characteristic

The speed-current characteristic is the relationship between current and speed. This curve is generally plotted on the same sheet as the speed-torque curve, using a common speed scale for both curves.

7.3.2 Speed-torque and speed-current curves procedure

Any one of the methods listed in 7.3.2.1 through 7.3.2.4 may be used to obtain data for a speed-torque curve. The selection of the method will depend upon the size and the speed-torque characteristics of the machine and the testing facilities. In all four methods, sufficient test points should be recorded to ensure that reliable curves, including irregularities, can be drawn in the regions of interest from the test data. It is important that the frequency of the power supply be maintained constant throughout the test. For wound-rotor motors, the slip rings shall be short-circuited for this test.

Method 1 and Method 4 require the maintenance of constant speed for each reading. Therefore, they cannot be used in regions where the torque of the machine increases with speed more rapidly than that of the loading device. From the results of the following tests, adjusted to the rated voltage, curves of torque and current should be plotted vs. speed.

7.3.2.1 Method 1—Measured output

A dc generator that has had its losses previously determined is coupled or belted to the motor being tested. An ac power supply of rated frequency is connected to the motor terminals. The voltage should be as high as can be impressed upon the motor terminals without excessive heating, at least 50% of rated voltage, if possible. The speed of the motor for each test point is controlled by varying the load on the generator.

In this test, readings are taken at speeds between approximately 1/3 synchronous speed and the maximum speed obtainable. The speed should be constant when the readings are taken, so that acceleration or deceleration power does not affect the results. At each speed setting, readings of voltage, current, and speed are taken for the induction motor, and readings of armature voltage and current and field current are taken for the dc generator. Care should be taken not to overheat the motor.

The accuracy of speed measurement is particularly important at low slip. All points should be read as soon as the meters have settled, without waiting for the slow creep in the indications to disappear.

The total power output of the motor is the sum of the power output and losses of the dc generator.

The torque, T, at each speed is calculated as shown in Equation (78).

$$T = \frac{k_2(P_{GO} + P_{GL})}{n} \tag{78}$$

where

T is torque, in N·m,
P_{GO} is the generator output, in W,
P_{GL} is the losses of the generator (including friction and windage), in W,
n is the test speed of motor, in r/min,
k_2 is 9.549 for torque in N·m.

At the speed for the test point, the values of torque and current are corrected to the specified voltage, V, as described in 7.3.3.

7.3.2.2 Method 2—Acceleration

In the acceleration method, the motor is started with no load, and the value of acceleration is determined at various speeds. The torque at each speed is determined from the acceleration of the mass of the rotating parts. Accurate measurements of speed and acceleration are an essential requirement of this method.

The acceleration to be used and the duration of the test are determined by the type of instruments that are used to make the measurements. In any case, the accelerating time should be long enough so that electrical transient effects in the instruments and in the motor do not distort the speed-torque curve. The accelerating time must also be long enough to permit recording the necessary number of mechanical and electrical measurements with sufficient accuracy for plotting the required curves (see 7.3.2).

To provide sufficient time for recording the data at each point, the accelerating time may be increased by using a lower applied voltage or by coupling a suitable inertia to the motor shaft.

As the motor accelerates from rest to near synchronous speed, simultaneous readings are taken of line-to-line voltage for one phase, line current in one phase, speed, and time in seconds. A minimum of five sets of readings should be taken during the accelerating period; however, more readings should be taken if possible. If the motor's starting friction is high, or if more accurate data in the zero speed range are desired, the motor can be started rotating in the reverse direction prior to application of power for the acceleration on which measurements are to be taken.

If Method 3 (see 7.3.2.3) is to be used as a check, line power should be taken with a polyphase wattmeter or two single-phase wattmeters at each speed point where data are recorded.

It may sometimes be necessary to take more than one run at different voltages in order to get satisfactory readings throughout the curve, especially when there are appreciable cusps in the speed-torque characteristics.

The torque, T, at each speed is calculated from the acceleration using Equation (79).

$$T = \frac{J}{k_2} \times \frac{dn}{dt} \tag{79}$$

where

T is torque, in N·m,

J is the moment of inertia of rotating parts, in kg · m^2,

$\frac{dn}{dt}$ is the acceleration at each speed, in revolutions per minute per second,

k_2 is 9.549 for torque in N·m.

At the speed for the test point, the values of torque and current are corrected to the specified voltage, V, as described in 7.3.3.

7.3.2.3 Method 3—Input

In this method, the torque is determined by subtracting the losses in the machine from the input power. It is a valuable check on the other methods, and is particularly useful when the machine cannot be unloaded to determine torque by acceleration. In practice, the method is approximate because the stator losses cannot be readily determined for the actual operating conditions and, therefore, must be approximated. This method is also subject to error in the case of special machines that may have substantial positive or negative harmonic torques that are not readily evaluated.

The machine is started as described in 7.3.2.2, except that it does not have to be unloaded. The input readings called for in 7.3.2.2 are plotted against the speed readings. The line voltage, line current, power, and speed should be plotted vs. time. Average values of the zero speed readings from the locked test, as described in 7.2.2, adjusted to the voltage at which the other readings were taken, should be included.

The torque, T, at each speed is determined from the input power using Equation (80).

$$T = \left\{\left[\frac{k_2}{n_s}\right] \times \left[P_{si} - P_{SIR} - P_h - P_{SLs} - P_{SLr} \times \sqrt{\frac{n}{n_s}}\right]\right\} - T_{fw} \tag{80}$$

where

T is torque, in N·m,

P_{si} is the input power to stator, in W,

P_{SIR} is the stator I^2R loss, in W, at the test current (see 5.2),

P_h is the core loss, in W, at the test voltage (see 5.5.5),

P_{SLs} is the fundamental frequency stray-load loss, in W, at the test current (see 5.7.2.1),

P_{SLr} is the higher frequencies stray-load loss, in W, at the test current (see 5.7.2.2),

n is test speed, in r/min,

n_s is the synchronous speed, in r/min,

k_2 is 9.549 for torque in N·m,

T_{fw} is the motor friction and windage torque at test speed, in N·m.

NOTE—If the P_{SLs} component of stray load loss is not available, it may be assumed that the stray load loss is equal to P_{SLr}. If the stray load loss (P_{SLs} + P_{SLr}) has been determined from a dynamometer test, the total value of stray-load loss may be used as the value of P_{SLr}; or, the value of P_{SLs} may be determined by the method outlined in 5.7.2.1, and P_{SLr} may be determined as the value of stray load loss minus the value of P_{SLs} .

At the speed for the test point, the values of torque and current are corrected to the specified voltage, V, as described in 7.3.3.

7.3.2.4 Method 4—Direct measurement

The torque and current are measured as the machine is loaded at various speeds with a dynamometer or mechanical brake. At each speed, simultaneous readings of voltage, current, speed, and torque are taken. The test should be taken as near rated voltage as practical. If a reduced voltage is used, the values of torque and current should be corrected to the specified voltage as described in 7.3.3.

7.3.3 Correction of data for tests performed at reduced voltage

When it is necessary to establish values of current and torque at rated voltage, based on speed-torque, speed-current, and locked-rotor tests made at reduced voltage, it should be recognized that, because of saturation of the leakage flux paths, the current may increase by a ratio somewhat greater than the first power of the voltage; and the torque may increase by a ratio somewhat greater than the square of the voltage. The relationship varies with design; however, as a first approximation, the current is calculated as varying directly with voltage, and torque with the square of voltage.

A more exact method of test requires determining the rate of change of current and torque with voltage by establishing speed-torque and speed-current curves for at least two, and preferably for three or more, values of voltage. The reduced-voltage test points should be plotted on log-log paper and corrected to rated voltage using a least square curve fit for maximum accuracy. On speed-torque and speed-current curves, enough points at various speeds must be corrected to provide true representation of the curve over the entire speed range.

8. Miscellaneous tests

8.1 Insulation resistance

For maintenance purposes, insulation resistance tests are of value. All accessories, such as surge capacitors, surge arresters, current transformers, etc., that have leads located at the machine terminals shall be disconnected during this test, with the leads connected together and to the frame or core.

For test methods, see IEEE Std 43-2000.

8.2 High-potential test

8.2.1 General

High-potential tests are tests that consist of the application of a voltage higher than the rated voltage for a specified time for the purpose of determining the adequacy against breakdown of insulating materials and spacings under normal conditions.

The test voltage should be applied when, and only when, the machine is in good condition and the insulation resistance is not impaired due to dirt, moisture, or abrasion or other types of damage. See IEEE Std 43-2000.

8.2.2 Measurement

For measurement of high-potential test voltage, see IEEE Std 4-1995 [B6]. The voltmeter method of measurement is commonly used.

8.2.3 Connections

The high-potential 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. Interconnected polyphase windings are considered as one circuit. All accessories such as surge arresters, current transformers, etc., that have leads located at the machine terminals shall be disconnected during this test, with the leads connected together and to the frame or core. No leads shall be left unconnected during the test as this may cause an extremely severe stress at some point of the winding.

8.2.4 Test voltage

The commonly specified high-potential test voltage for factory testing of new stators is 1000 volts plus 2 times the rated voltage of the machine. Likewise for new rotors of wound rotor machines the test voltage is 1000 volts plus 2 times the maximum voltage induced between collector rings. Refer to NEMA MG 1- 2003 [B7] Part 12 and Part 20 to confirm the voltage level for the specific machine under test.

Since high-potential testing is stressful on winding dielectric components, it is recommended that initial field high-potential test voltages be limited to 85% of the levels used for factory testing of new equipment. For any further high potential testing, it is recommended the test voltage level be limited to a 75% level.

8.2.5 Voltage application

In performing the test, the voltage shall be increased to full value as rapidly as possible while still maintaining an accurate meter reading, and the full voltage should be maintained for 1 min. It should then be reduced at a rate that will bring it to 1/4 value or less in not more than 15 seconds.

To avoid excessive stressing of the insulation components, repeated application of the high-potential test voltage is not recommended.

WARNING

Due to the high voltage used, high-potential tests should be conducted only by experienced personnel, and adequate safety precautions should be taken to avoid injury to personnel and damage to property. For the procedures recommended, refer to IEEE Std 4-1995 [B6].

8.3 Shaft current and voltage

Shaft currents can flow in rotating machinery as a consequence of electromagnetically developed voltages in the shaft or frame.

In electrical machines, any unbalance in the magnetic circuits, or in the electrical phase currents that encircle a shaft, can create flux linkages with the rotating system. When the shaft rotates, these linkages can produce an electric potential difference between shaft ends. This voltage is capable of driving a circulating current in a shaft-to-frame loop by using two bearings to complete the circuit.

If the opposite drive end bearing (or both bearings) is/are isolated from the frame, the conducting path is impeded by the insulation, and the circulating shaft current in that machine is inhibited. If only the drive end bearing is insulated, however, the current may be able to circulate by using the opposite end bearing in conjunction with an uninsulated bearing in the interconnected equipment to complete the circuit.

8.3.1 Test to measure shaft potential for circulating shaft currents

In machines that have insulation on all bearings (or all but one bearing), a test can be conducted to detect the presence of shaft potential while the unit is operating. This test can also be applied to machines that have insulating properties in all bearing oil films.

The test is completed by measuring the shaft potential to the frame at each of the other bearings. A high impedance oscilloscope should be utilized and connected with one lead grounded to the frame and the other lead attached to a shaft brush. This brush is then applied to a shaft section near each bearing and the peak voltages are measured. First, a shaft brush is used to short out the uninsulated bearing (or one bearing, if all are insulated). This fixed brush is applied to the shaft near the bearing and connected to the frame with a short piece of low-resistance conductor.

It is preferable to use a low-impedance shielded conductor for the oscilloscope leads to minimize electromagnetic interference. This shield should be grounded at one end only.

If an oscilloscope is not available for the test, a high-impedance voltmeter can be used. Both ac and dc voltages should be measured at each bearing. The peak voltage can be roughly approximated by adding the dc level and 1.4 times the ac rms level. This estimated peak voltage, however, may be considerably below the actual peak value.

An alternate method involves measuring the ac voltage with brushes contacting opposite ends of the shaft while the machine is operating at rated voltage and speed.

8.3.2 Test to measure possible level of shaft current

This test can be conducted on machines as described in 8.3.1. The procedure is identical to that of 8.3.1, with the exception that a low-resistance ammeter is used in place of the oscilloscope.

NOTE—In this test arrangement, the ammeter is being used as a low-impedance, uncalibrated voltmeter. The meter readings may not be a true indication of the current that might flow should there be a breakdown of the lubrication film in the bearing(s). This method may be useful if a history of results from similar tests is available.

8.3.3 Other methods

If special means for measurement of shaft currents, such as Rogowski loops, are a feature of the machine under test, these may be used in lieu of or to supplement the above test methods.

8.4 Bearing insulation resistance

8.4.1 Method 1

The most reliable check on bearing insulation is performed with the unit at rest. If only one bearing is insulated, a layer of insulating paper should be applied under the uninsulated bearing journal to insulate the shaft from the bearing. Couplings to adjacent units should be disengaged if they are not insulated.

A low-voltage ohmmeter should be used to make a preliminary check at each insulated bearing. With one ohmmeter lead applied to the shaft and the other to the frame (across the insulation), the bearing insulation resistance can be measured.

On machines with two layers of bearing insulation and with a metallic separator between layers, this test should be performed between the metallic separator and the machine frame. The test can be conducted while the machine is running, but it is preferable to conduct the test with the machine at rest. The test should be supplemented with a careful visual inspection to ensure that there are no possible parallel paths that are uninsulated.

8.4.2 Method 2

A layer of heavy paper is placed around the shaft to insulate the journals of the uninsulated bearings. The coupling of the driving or driven units should be disengaged, if it is not insulated. Then, from a 110–125 V source with either a filament lamp suitable for the circuit voltage or a voltmeter of approximately 150 V full scale with a resistance in the range of 100–300 Ω/V placed in series with the voltage source, two leads should be run, one to the insulated bearing and the other to the frame (across the insulation). If the lamp filament does not show color (or if the reading of the, voltmeter does not exceed 60 V), the insulation may be considered satisfactory.

A 500 V megohmmeter may also be used. This is much more sensitive than the above method and may tend to reject insulation, which, in reality, is adequate to prevent the small shaft voltage from causing injurious current. See 8.4.1.

8.5 Noise

For noise (sound level) tests refer to NEMA MG 1–2003 [B7] Part 9 and IEC 60034-9 [B3].

8.6 Balance and vibration

8.6.1 Rotor balance

Motor and generator rotors should be dynamically balanced with a half key in place.

8.6.2 Vibration

For vibration tests, refer to NEMA MG 1–2003 [B7] Part 7, IEC 60034-14 [B4] or API Std 541, 4th Edition [B2].

8.7 Overspeed

When overspeed tests are performed, precautions shall be taken to protect personnel and equipment.

9. Forms

9.1 Test forms and support information

This test procedure does not require that the test forms presented must be used, however, the forms and supporting information do show the sequence of tests that must be used and do guide the calculations with equations using the line item numbers from the forms. It is expected that the test analyses will be accomplished using computer programs and in many cases with data being obtained by electronic means and going directly into the analysis program.

9.1.1 Summary of characteristics

A table or listing of the summary of characteristics is a part of each test form. With most of the test methods, the values at specific load values are obtained from plots of the calculated values of the test points. From a curve defined by these points, the values for the points of interest may be obtained. Load values of 25, 50, 75, 100, 125, and 150 percent of rated load are commonly used. Any other load of interest can also be shown. The power factor here is calculated for each precise load point using the voltage, current, and power obtained from the plotted data. The data plots mentioned may be a manual or a computer generated plot or the required data values at the specific load points may be calculated from a computerized virtual curve if such programs are available. Data summaries for Method F testing may be calculated for the precise desired points; a plot of the data is not necessary.

9.2 Form A–Method A

Type _____________Design ________________ Frame __________________Rating ___________________Phase ______________
Frequency______________ Volts _______________Synchronous r/min __________________________Serial No. ______________
Degrees C Temperature Rise __________________ Time Rating_______________________________ Model No. ______________

Specified temperature, t_S, _______ in °C	Synchronous speed, n_s________ in r/min		Stator Resistance, Terminal-to-Terminal ______ Ohms @ ______ °C			
Test Point (Motoring)(Generating)	1	2	3	4	5	6
Stator Winding Temperature, t_t, in °C						
Ambient Temperature, in °C						
Line-to-Line Voltage, in V						
Frequency, in Hz						
Observed Speed, in r/min						
Observed Slip, in r/min						
Observed Slip, in p.u.						
Corrected Slip, in p.u.						
Corrected Speed, in r/min						
Torque, in N·m						
Dynamometer Correction, in N·m						
Corrected Torque, in N·m						
Shaft Power, in W						
Line Current, in A						
Stator Power, in W						
(a) Stator I^2R Loss, in W, at t_t						
(b) Stator I^2R Loss, in W, at t_s						
Stator Power Correction = (b) – (a)						
Corrected Stator Power, in W						
Efficiency, in %						
Power Factor, in %						

Performance Curve ____

Summary of Characteristics

Load, in % of rated	25	50	75	100	125	150
Power Factor, in %						
Efficiency, in %						
Speed, in r/min						
Line Current, in A						

9.3 Form A2–Method A calculations

Type _____________Design ________________ Frame __________________Rating ___________________Phase ______________
Frequency______________Volts _______________Synchronous r/min ___________________________Serial No. ______________
Degrees C Temperature Rise _________________________ Time Rating ________________________ Model No. ______________

Specified temperature, t_s, __(1)__, in ˚C. See 3.3.2.		Synchronous speed, n_s, ____(2)___, in r/min	Stator Resistance, Terminal-to-Terminal ___(3)___Ohms @ ___(4)___°C See6.3.1.1			
Item	Test Point (Motoring)(Generating)	Source or Calculation	1	2	--	6
5	Stator Winding Temp, t_t in ˚C	From each test point. From 6.3.1.3				
6	Ambient Temperature, in ˚C	From each test point. From 6.3.1.3				
7	Line-to-Line Voltage, in V	From each test point. From 6.3.1.3				
8	Frequency, in Hz	From each test point. From 6.3.1.3				
9	Observed Speed, in r/min	# (9) = (2) – (10)				
10	Observed Slip, in r/min	# (10) = (2) – (9)				
11	Observed Slip, in p.u.	(11) = (10) / (2)				
12	Corrected Slip, in p.u.	See 5.3.2				
13	Corrected Speed, in r/min	(13) = (2) × [1-(12)]				
14	Torque, in N·m	From each test point. From 6.3.1.3				
15	Dynamometer Correction, in N·m	From calculation per 5.6.1.2				
16	Corrected Torque, in N·m	For motoring: (16) = (14) + (15) For generating: (16) = (14) – (15)				
17	Shaft Power, in W	(17) = (16) × (13) / 9.549				
18	Line Current, in A	From each test point. From 6.3.1.3				
19	Stator Power, in W	From each test point. From 6.3.1.3				
20	Stator I^2R Loss, in W, at t_t	$*(20) = 1.5 \times (18)^2 \times (3) \times \{[k_1 + (5)]/[k_1 + (4)]\}$				
21	Winding Resistance at t_s	Correct (3) using Equation (3)				
22	Stator I^2R Loss, in W, at t_s	$(22) = 1.5 \times (18)^2 \times (21)$				
23	Stator Power Correction	(23) = (22) – (20)				
24	Corrected Stator Power, in W	For motoring: (24) = (19) + (23) For generating: (24) = (19) – (23)				
25	Efficiency, in %	For motoring: (25) = 100 (17)/(24) For generating: (25) = 100 (24)/(17)				
26	Power Factor, in %	(26) = 100 × (24) / [1.732 × (7) × (18)]				

Enter the measured speed or measured slip for each test point on the proper line and use formulas provided to calculate the other parameter.

* In (20) select k_1 based on the stator conductor material. See 5.2.1.

Parentheses, ( ), normally used with equation numbers are not used here to avoid confusion with the form item numbers.

9.4 Form B–Method B

Type _____________Design ________________ Frame __________________Rating ___________________Phase ______________
Frequency______________ Volts _______________Synchronous r/min __________________________Serial No. ______________
Degrees C Temperature Rise _________________________ Time Rating ________________________ Model No. ______________

Cold Stator Winding Resistance Between Terminals ______________ Ohms @ _______________°C

Rated Load Temp. Test Stator Winding Resistance Between Terminals_______Ohms @ ____°C in ____°C Ambient
Rated Load Temperature Test Stator Temperature Rise ________ °C
Total Stator Temperature, t_s ________ °C in a 25 °C Ambient

Description (Motoring)(Generating)	1	2	3	4	5	6
Ambient Temperature, in ˚C						
Stator Winding Temperature, t_t, in ˚C						
Frequency, in Hz						
Synchronous Speed, in r/min						
Speed, in r/min						
Slip Speed, in r/min						
Slip in p.u.						
Line-to-Line Voltage, in V						
Line Current, in A						
Stator Power, in W						
Core Loss, in W						
Stator I^2R Loss, in W, at t_t						
Power Across Air Gap, in W						
Rotor I^2R Loss, in W						
Friction and Windage Loss, in W						
Total Conventional Loss, in W						
Torque, in N·m						
Dynamometer Correction, in N·m						
Corrected Torque, in N·m						
Shaft Power, in W						
Apparent Total Loss, in W						
Stray-Load Loss, in W						
Intercept _____________ Slope _____________Correlation Factor _____________ Point Deleted___________________						
Stator I^2R Loss, in W, at t_s						
Corrected Power Across Air Gap, in W						
Corrected Slip, in p.u.						
Corrected Speed, in r/min						
Rotor I^2R Loss, in W, at t_s						
Corrected Stray-Load Loss, in W						
Corrected Total Loss, in W						
Corrected Shaft Power, in W						
Efficiency, in %						
Power Factor, in %						

The Summary of Characteristics shall be presented as with Form A in 9.2. For additional guidance, see 9.1.1.

9.5 Form B2–Method B calculations

Cold Stator Winding Resistance Between Terminals ___(1)____ Ohms @ ____(2)____°C From 6.4.1.1

Hot Stator Winding Resistance Between Terminals __(3)__Ohms @ __(4)__°C in __(5)__°C Ambient From 6.4.1.2

Rated Load Temp. Test Stator Temperature Rise __(6)__ °C, (6) = (4) – (5)

(4) ={[(3) / (1)] × [k_1 + (2)]} – k_1

Total Stator Temperature, t_s, __(7)__ °C in a 25 °C Ambient, (7) = (6) + 25

If (6) & (7) are from duplicate, (3), (4) & (5) are N/A

Item	Description (Motoring)(Generating)	Source or Calculation	
8	Ambient Temperature, in ˚C	From each test point, from 6.4.1.3	
9	Stator Winding Temperature, t_t, in ˚C	From each point, adjusted per 6.4.2.4	
10	Frequency, in Hz	From each test point, from 6.4.1.3	
11	Synchronous Speed, in r/min	=120 × (10) / number of poles	
12	Speed, in r/min	*= (11) – (13)	
13	Slip Speed, in r/min	*= (11) – (12)	
14	Slip in p.u.	= (13) / (11)	
15	Line-to-Line Voltage, in V	From each test point, from 6.4.1.3	
16	Line Current, in A	From each test point, from 6.4.1.3	
17	Stator Power, in W	From each test point, from 6.4.1.3	
18	Core Loss, in W	From 5.5.5 at voltage equal to (15)	
19	Stator I^2R Loss, in W,	= 1.5 × $(16)^2$ × R , Adjust R see 6.4.2.4	
20	Power Across Air Gap, in W	= (17) – (18) – (19) for motor = (17) + (18) + (19) for generator	
21	Rotor I^2R Loss, in W	= (20) × (14)	
22	Friction and Windage Loss, in W	From 5.5.4	
23	Total Conventional Loss, in W	= (18) + (19) + (21) + (22)	
24	Torque, in N·m	From each test point, from 6.4.1.3	
25	Dynamometer Correction, in N·m	From test per 5.6.1.2, if needed	
26	Corrected Torque, in N·m	= (24) + (25)	
27	Shaft Power, in W	= (26) × (12) / 9.549	
28	Apparent Total Loss, in W	= (17) – (27) for a motor = (27) – (17) for a generator	
29	Stray-Load Loss, in W	= (28) – (23)	

Intercept ____(30)_____ Slope ____(31)___ Correlation Factor ____(32)_____ Point Deleted ____(33)_____
(30), (31), (32) & (33) from the linear regression analysis of (29) & (26) entries as described in 6.4.2.8

34	Stator I^2R Loss, in W, at t_s	= 1.5 × $(16)^2$ × (3) × {[k_1 + (7)] / [k_1 + (4)]}	
35	Corrected Power Across Air Gap, in W	= (17) – (18) – (34)	
36	Corrected Slip, in p.u.	= (14) × [k_1 + (7)] / [k_1 + (9)]	
37	Corrected Speed, in r/min	= (11) × [1.00 – (36)]	
38	Rotor I^2R Loss, in W, at t_s	= (36) × (35)	
39	Corrected Stray-Load Loss, in W	= (31) × $(26)^2$	
40	Corrected Total Loss, in W	= (18) + (22) + (34) +(38) + (39)	
41	Corrected Shaft Power, in W	= (17) – (40)	
42	Efficiency, in %	= 100(41)/(17) for a motor = 100(17)/(41) for a generator	
43	Power Factor, in %	= 100 × (17) / [1.732 × (15) × (16)]	

*Enter the measured speed or measured slip speed for each test point on the proper line and use the formula provided to calculate the other parameter. In (4), (19), (34), and (36), select k_1 based on conductor material. See 5.2.1 and 5.3.2. See 9.1.1 for Summary of Characteristics.

9.6 Form B1–Method B1

Type _____________Design ________________ Frame __________________Rating ___________________Phase ______________

Frequency______________ Volts _______________Synchronous r/min __________________________Serial No. ______________

Degrees C Temperature Rise _________________________ Time Rating _________________________Model No.______________

Cold Stator Winding Resistance Between Terminals ______________ Ohms @ _______________°C						
Specified Stator Temperature, t_s ________ °C in a 25 °C Ambient						
Description (Motoring)(Generating)	1	2	3	4	5	6
Ambient Temperature, in ˚C						
Stator Winding Temp, (t_t), in ˚C						
Frequency, in Hz						
Synchronous Speed, in r/min						
Speed, in r/min						
Slip Speed, in r/min						
Slip in p.u.						
Line-to-Line Voltage, in V						
Line Current, in A						
Stator Power, in W						
Core Loss, in W						
Stator I^2R Loss, in W, at t_t						
Power Across Air Gap, in W						
Rotor I^2R Loss, in W						
Friction and Windage Loss, in W						
Total Conventional Loss, in W						
Torque, in N·m						
Dynamometer Correction, in N·m						
Corrected Torque, in N·m						
Shaft Power, in W						
Apparent Total Loss, in W						
Stray-Load Loss, in W						
Intercept _____________ Slope _____________Correlation Factor_ __________________ Point Deleted_______________						
Stator I^2R Loss, in W, at t_s						
Corrected Power Across Air Gap, in W						
Corrected Slip, in p.u.						
Corrected Speed, in r/min						
Rotor I^2R Loss, in W, at t_s						
Corrected Stray-Load Loss, in W						
Corrected Total Loss, in W						
Corrected Shaft Power, in W						
Efficiency, in %						
Power Factor, in %						

The Summary of Characteristics shall be presented as with Form A in 9.2. For additional guidance, see 9.1.1.

9.7 Form B1-2–Method B1 calculations

Cold Stator Winding Resistance Between Terminals ____(1)_____ Ohms @ ____(2)____°C From 6.5.1.1			
Specified Stator Temperature, (t_s), __(3)___ °C in a 25 °C Ambient, From 3.3.2 c)			
Item	Description (Motoring)(Generating)	Source or Calculation	
4	Ambient Temperature, in ˚C	From each test point, from 6.5.1.4	
5	Stator Winding Temp, t_t, in ˚C	From each test point, from 6.5.1.4	
6	Frequency, in Hz	From each test point, from 6.5.1.4	
7	Synchronous Speed, in r/min	=120 × (6) / number of poles	
8	Speed, in r/min	*= (7) – (9)	
9	Slip Speed, in r/min	*= (7) – (8)	
10	Slip in p.u.	= (9) / (7)	
11	Line-to-Line Voltage, in V	From each test point, from 6.5.1.4	
12	Line Current, in A	From each test point, from 6.5.1.4	
13	Stator Power, in W	From each test point, from 6.5.1.4	
14	Core Loss, in W	From 5.3.5 at voltage equal to (11)	
15	Stator I^2R Loss, in W, at t_t	= 1.5 × $(12)^2$ × (1) × {[k_1 + (5)] / [k_1 + (2)]}	
16	Power Across Air Gap, in W	= (13) – (14) – (15) for a motor = (13) + (14) + (15) for a generator	
17	Rotor I^2R Loss, in W	= (16) × (10)	
18	Friction and Windage Loss, in W	From 5.5.4	
19	Total Conventional Loss, in W	= (14) + (15) + (17) + (18)	
20	Torque, in N·m	From each test point, from 6.5.1.4	
21	Dynamometer Correction, in N·m	From test per 5.6.1.2, if needed	
22	Corrected Torque, in N·m	= (20) + (21)	
23	Shaft Power, in W	= (22) × (8) / 9.549	
24	Apparent Total Loss, in W	= (13) – (23) for a motor = (23) – (13) for a generator	
25	Stray-Load Loss, in W	= (24) – (19)	
Intercept ____(26)____Slope ____(27)____Correlation Factor ____(28)____Point Deleted ____(29)_____ (26), (27), (28) & (29) from the linear regression analysis of (25) & (22) entries as described in 6.4.2.7			
30	Stator I^2R Loss, in W, at t_s	= 1.5 × $(16)^2$ × (1) × {[k_1 + (3)] / [k_1 + (2)]}	
31	Corrected Power Across Air Gap, in W	= (13) – (14) – (30)	
32	Corrected Slip, in p.u.	= (10) × [k_1 + (3)] / [k_1 + (5)]	
33	Corrected Speed, in r/min	= (7) × [1.00 – (32)]	
34	Rotor I^2R Loss, in W, at t_s	= (31) × (32)	
35	Corrected Stray-Load Loss, in W	= (27) × $(22)^2$	
36	Corrected Total Loss, in W	= (14) + (18) + (30) +(34) + (35)	
37	Corrected Shaft Power, in W	= (13) – (36)	
38	Efficiency, in %	=100(37)/(13) for a motor = 100(13)/(37) for a generator	
39	Power Factor, in %	= 100 × (13) / [1.732 × (11) × (12)]	

*Enter the measured speed or measured slip speed for each test point on the proper line and use the formula provided to calculate the other parameter. In (15), (30), and (32), select k_1 based on conductor material. See 5.2.1 and 5.3.2. See 9.1.1 for Summary of Characteristics.

9.8 Form C–Method C

Type _____________Design ________________ Frame __________________hp/kW ___________________Phase ______________
Frequency______________ Volts _______________ Speed r/min________________________________Serial No. ______________
Degrees C Temperature Rise _________________________ Time Rating _________________________Model No.______________

M1	Average Cold Stator Winding Resistance Between Terminals _________ Ohms @ __________°C											
M2	Average Cold Stator Winding Resistance Between Terminals _________ Ohms @ __________°C											
Total Specified Stator Temperature, t_s ________ °C in a 25 °C Ambient												
Test Point >	1		2		3		4		5		6	
Description	M 1	M 2	M 1	M 2	M 1	M 2	M 1	M 2	M 1	M 2	M 1	M 2
Part A of Test Point – Machine 1 as a motor and Machine 2 as a generator												
Ambient Temperature, in ˚C												
Stator Winding Temp, t_t, in ˚C												
Frequency, in Hz												
Synchronous Speed, in r/min												
Speed, in r/min												
Slip Speed, in r/min												
Slip, in p.u.												
Line-to-Line Voltage, in V												
Volts / Hertz												
Line Current, in A												
Stator Power, in W												
Core Loss, in W												
Stator I^2R Loss, in W, at t_t												
Power Across the Air Gap, in W												
Rotor I^2R Loss, in W												
Friction and Windage Loss, in W												
Total Conventional Loss, in W												
Rotor Current, in A												
Combined Stray-Load Loss, in W												
Stray-Load Loss, in W												
Part B of Test Point – Machine 1 as a generator and Machine 2 as a motor												
Ambient Temperature, in ˚C												
Stator Winding Temp, t_t, in ˚C												
Frequency, in Hz												
Synchronous Speed, in r/min												
Speed, in r/min												
Slip Speed, in r/min												
Slip, in p.u.												
Line-to-Line Voltage, in V												
Volts / Hertz												
Line Current, in A												
Stator Power, in W												
Core Loss, in W												
Stator I^2R Loss, in W, at t_t												

Form C, Part 1

Test Point >	1		2		3		4		5		6	
Description	M 1	M 2	M 1	M 2	M 1	M 2	M 1	M 2	M 1	M 2	M 1	M 2
Power Across the Air Gap, in W												
Rotor I^2R Loss, in W												
Friction and Windage Loss, in W												
Total Conventional Loss, in W												
Rotor Current, in A												
Combined Stray-Load Loss, in W												
Stray-Load Loss, in W												
	Machine 1						**Machine 2**					
	1	2	3	4	5	6	1	2	3	4	5	6
Average Rotor Current, in A												
Average Stray-Load Loss, in W												
Linear Regression Analysis												
Machine 1 – Intercept ____________ Slope ______________ Correlation Factor ______________												
Machine 2 – Intercept ____________ Slope ______________ Correlation Factor ______________												
Corrected Values												
Stator I^2R Loss, in W, at t_s												
Power Across Air Gap, in W												
Slip, in p.u.												
Speed, in r/min												
Rotor I^2R Loss, in W, at t_s												
Stray-Load Loss, in W												
Total Loss, in W												
Shaft Power, in W												
Efficiency, in %												

Summary of Characteristics
Machine 1

Load, in % of rated	25	50	75	100	125	150
Power Factor, in %						
Efficiency, in %						
Speed, in r/min						
Line Current, in A						

Summary of Characteristics
Machine 2

Load, in % of rated	25	50	75	100	125	150
Power Factor, in %						
Efficiency, in %						
Speed, in r/min						
Line Current, in A						

Form C, Part 2

9.9 Form C2–Method C Calculations

Type ____________Design _______________ Frame _________________hp/kW __________________Phase _____________

Frequency_____________ Volts ______________Speed r/min______________________________Serial No. _____________

Degrees C Temperature Rise _______________________ Time Rating _______________________Model No._____________

M1	Average Cold Stator Winding Resistance Between Terminals ____(1)____ Ohms @ ___(2)___°C			
M2	Average Cold Stator Winding Resistance Between Terminals ____(3)____ Ohms @ ___(4)___°C			
Total Specified Stator Temperature, t_s ____(5)____ °C in a 25 °C Ambient				
Item		Test Point>	**1, Etc.**	
M1	M2	Description	Machine 1	Machine 2
Part A of Test Point – Machine 1 as a motor and Machine 2 as a generator				
6	26	Ambient Temperature, in ˚C	From each test point, from 6.6.1.3	From each test point, from 6.6.1.3
7	27	Stator Winding Temp, t_t , in ˚C	From each test point, from 6.6.1.3	From each test point, from 6.6.1.3
8	28	Frequency, in Hz	From each test point, from 6.6.1.3	From each test point, from 6.6.1.3
9	29	Synchronous Speed, in r/min	(9) = 120 × (8) / No. of poles	(29) = 120 × (28) / No. of poles
10	30	Speed, in r/min	From each test point, from 6.6.1.3	From each test point, from 6.6.1.3
11	31	Slip Speed, in r/min	From 6.6.1.3 or = (9) – (10)	From 6.6.1.3 or = (30) – (29)
12	32	Slip, in p.u.	(12) = (11) / (9)	(32) = (31) / (29)
13	33	Line-to-Line Voltage, in V	From each test point, from 6.6.1.3	From each test point, from 6.6.1.3
14	34	Volts / Hertz	(14) = (13) / (8)	(34) = (33) / (28)
15	35	Line Current, in A	From each test point, from 6.6.1.3	From each test point, from 6.6.1.3
16	36	Stator Power, in W	From each test point, from 6.6.1.3	From each test point, from 6.6.1.3
17	37	Core Loss, in W	From 6.6.2.3 for machine 1	From 6.6.2.3 for machine 2
18	38	Stator I^2R Loss, in W, at t_t	From 6.6.2.4 for machine 1	From 6.6.2.4 for machine 2
19	39	Power Across the Air Gap, in W	(19) = (16) – (17) – (18)	(39) = (36) + (37) + (38)
20	40	Rotor I^2R Loss, in W	(20) = (19) × (12)	(40) = (39) × (32)
21	41	Friction and Windage Loss, in W	From 6.6.2.2 for machine 1	From 6.6.2.2 for machine 2
22	42	Total Conventional Loss, in W	(22) = (17) + (18) + (20) + (21)	(42) = (37) + (38) + (40) + (41)
23	43	Rotor Current, in A	For each test point using Eq. 71	For each test point using Eq. 71
24		Combined Stray-Load Loss, in W	(24) = (16) – (36) – (22) – (42)	
25	44	Stray-Load Loss, in W	(25) = (20) × (24) / [(20) + (40)]	(44) = (24) – (25)
Part B of Test Point – Machine 1 as a generator and Machine 2 as a motor				
45	63	Ambient Temperature, in ˚C	From each test point, from 6.6.1.3	From each test point, from 6.6.1.3
46	64	Stator Winding Temp, t_t , in ˚C	From each test point, from 6.6.1.3	From each test point, from 6.6.1.3
47	65	Frequency, in Hz	From each test point, from 6.6.1.3	From each test point, from 6.6.1.3
48	66	Synchronous Speed, in r/min	(48) = 120 × (47) / No. of poles	(66) = 120 × (65) / No. of poles
49	67	Speed, in r/min	From each test point, from 6.6.1.3	From each test point, from 6.6.1.3
50	68	Slip Speed, in r/min	From 6.6.1.3 or = (49) – (48)	From 6.6.1.3 or = (66) – (67)
51	69	Slip, in p.u.	(51) = (50) / 48)	(69) = (68) / (66)
52	70	Line-to-Line Voltage, in V	From each test point, from 6.6.1.3	From each test point, from 6.6.1.3
53	71	Volts / Hertz	(53) = (52) / (47)	(71) = (70) / (65)
54	72	Line Current, in A	From each test point, from 6.6.1.3	From each test point, from 6.6.1.3
55	73	Stator Power, in W	From each test point, from 6.6.1.3	From each test point, from 6.6.1.3
56	74	Stator I^2R Loss, in W, at t_t	From 6.6.2.4 for machine 1	From 6.6.2.4 for machine 2
57	75	Power Across the Air Gap, in W	(57) = (55) + (17) + (56)	(75) = (73) – (37) – (74)

Form C2, Part 1

M1	M2	Description	Machine 1	Machine 2
57	75	Power Across the Air Gap, in W	(57) = (55) + (17) + (56)	(75) = (73) – (37) – (74)
58	76	Rotor I^2R Loss, in W	(58) = (57) × (51)	(76) = (75) × (68)
59	77	Total Conventional Loss, in W	(59) = (17) + (21)+ (56) + (58)	(77) = (37) + (41) + (74) + (76)
60	78	Rotor Current, in A	For each test point using Eq. 71	For each test point using Eq. 71
61		Combined Stray-Load Loss, in W	(61) = (55) – (73) – (59) – (77)	
62	79	Stray-Load Loss, in W	(62) = (61) – (79)	(79) = (76) × (61) / [(58) + (76)]
Combination of Part A and Part B Data				
			Machine 1	Machine 2
80	82	Average Rotor Current, in A	(80) = [(23) + (60)] / 2	(82) = [(43) + (78)] / 2
81	83	Average Stray-Load Loss, in W	(81) = [(25) + (62)] / 2	(83) = [(44) + (79)] / 2
Linear Regression Analysis				
Machine 1 – Intercept _____(84)______ Slope _____(85)______ Correlation Factor _____(86)_____				
Machine 2 – Intercept _____(87)______ Slope _____(88)______ Correlation Factor _____(89)_____				
Corrected Values				
90	99	Stator I^2R Loss, in W, at t_s	As in (18) with R at t_s	As in (38) with R at t_s
91	100	Power Across Air Gap, in W	(91) = (16) – (17) – (90)	(100) = (36) – (37) – (99)
92	101	Slip, in p.u.	(12) Corrected as in 5.3.2	(32) Corrected as in 5.3.2
93	102	Speed, in r/min	(93) = (9) × [1.00 – (92)]	(102) = (29) × [1.00 – (101)]
94	103	Rotor I^2R Loss, in W, at t_s	(94) = (93) × (92)	(103) = (102) × (101)
95	104	Stray-Load Loss, in W	(95) = (85) × $(80)^2$	(104) = (88) × $(82)^2$
96	105	Total Loss, in W	(96) = (90) + (94) + (95) + (17) + (21)	(105) = (99) + (103) + (104) + (37) + (41)
97	106	Shaft Power, in W	(97) = (16) – (96)	(106) = (36) – (105)
98	107	Efficiency, in %	(98) = 100 × (97) / (16)	(107) = 100 × (106) / (36)

Parentheses, ( ), normally used with equation numbers are not used here to avoid confusion with the form item numbers.

Summary of Characteristics

Machine 1 [Machine 2 similar but not shown here. See Form C.]

Load, in % of rated	25	50	75	100	125	150
Power Factor, in %						
Efficiency, in %						
Speed, in r/min						
Line Current, in A						

Plot the line current, speed, and efficiency vs. output watts and then select values for these same quantities at precise load points to obtain the summary of characteristics. The power factor is computed for each precise load point from its amperes, volts, and input watts. The input power for the power factor calculation is: input power = 100 × output power from curve/efficiency in percent.

Form C2, Part 2

9.10 Form E–Method E-E1

Type _____________Design ________________ Frame __________________Rating ___________________Phase ______________
Frequency______________ Volts _______________ Synchronous r/min __________________________Serial No. ______________
Degrees C Temperature Rise _________________________Time Rating _______________________ Model No. ____________

Description (Motoring)(Generating)	1	2	3	4	5	6
Ambient Temperature, in ˚C						
†Stator Winding Temperature, t_t, in ˚C						
Frequency, in Hz						
Synchronous Speed, n_S in r/min						
Observed Speed, in r/min						
Observed Slip, in r/min						
Corrected Slip, in r/min						
Corrected Speed, in r/min						
Line-to-Line Voltage, in V						
Line Current, in A						
Stator Power, in W						
Core Loss, in W						
Winding resistance corrected to t_s						
Stator I^2R Loss, in W, at t_s						
Power Across the Gap, in W						
Rotor I^2R Loss, in W						
Friction and Windage Loss, in W						
Rotor Current, in A						
*Stray-Load Loss, in W						
Total Loss, in W						
Shaft Power, in W						
Efficiency, in %						
Power Factor, in %						

*Method E see 5.7.2 or 5.7.3, Method E1 See 5.7.4

†t_t = temperature of stator winding as determined from stator resistance or temperature detectors during test.

Summary of Characteristics

Load, in % of rated	25	50	75	100	125	150
Power Factor, in %						
Efficiency, in %						
Speed, in r/min						
Line Current, in A						

9.11 Form E2–Method E-E1 calculations

Type _____________Design ________________ Frame _________________Rating __________________Phase ______________
Frequency______________Volts _______________Synchronous r/min __________________________Serial No. ______________
Degrees C Temperature Rise ____________________Time Rating _____________________________ Model No. ______________

Cold Stator Winding Resistance Between Terminals (1)_________ Ohms @ (2) __________°C From 6.7.1.1			
Specified Stator Temperature, t_s, __(3)__ °C in a 25 °C Ambient, From 3.3.2 c)			
(Test)(Standard) Stray-Load Loss, (P'_{SL}) = ____(4)____*in W @, I'_2, ____(5)____A			
Item	Description (Motoring)(Generating)	Source or Calculation	
6	Ambient Temperature, in °C	From test of 6.7.1.2	
7	†Stator Winding Temp, t_t, in °C	From each point of test 6.7.1.2	
8	Frequency, in Hz	Line frequency	
9	Synchronous Speed, in r/min	= 120 × (8) / number of poles	
10	Observed Speed, in r/min	From each point of test 6.7.1.2	
11	Observed Slip, in p.u.	=[(9) – (10)] / (9)	
12	Corrected Slip, in p.u.	(10) corrected per 5.3.2	
13	Corrected Speed, in r/min	[1 – (12)] × (9)	
14	Line-to-Line Voltage, in V	From each point of test 6.7.1.2	
15	Line Current, in A	From each point of test 6.7.1.2	
16	Stator Power, in W	From each point of test 6.7.1.2	
17	Core Loss, in W	From 6.7.2.3	
18	Winding resistance corrected to t_s	Correct (1) per 5.2.1	
19	Stator I^2R Loss, in W, at t_s	= 1.5 × $(15)^2$ × (18)	
20	Power Across the Gap, in W	= (16) – (17) – (19)	
21	Rotor I^2R Loss, in W	= (12) × (20)	
22	Friction and Windage Loss, in W	= From 6.7.2.2	
23	Rotor Current, in A	From Equation 23 using (15) and I_0	
24	Stray-Load Loss, in W	See 5.7.2.5 for Method E or 5.7.4 for Method E1	
25	Total Loss, in W	= (17) + (19) + (21) + (22) + (24)	
26	Shaft Power, in W	For motor: = (16) – (25) For generator: = (16) + (25)	
27	Efficiency, in %	For motor: = 100 × (26) / (16) For generator: = 100 × (16) / (26)	
28	Power Factor, in %	= 100 × (16) / [1.732 × (14) × (15)]	

† t_t = temperature of stator winding as determined from stator resistance or temperature detectors during test.

Parentheses, ( ), normally used with equation numbers are not used here to avoid confusion with the form item numbers.

9.12 Form F–Methods F, F1, C/F, E/F, and E1/F1

Serial No. ____________________________________ Model No. ____

Type ________ Rating ___________ Voltage _________ Synchronous Speed _________ Phase __________ Frequency ___________

Description (Motoring)(Generating)		1	2	3	4	5	6
s	Slip in p.u.						
R_2/s	Effective rotor resistance						
X_2	Rotor reactance						
Z_2^2	Rotor impedance						
G_1	Rotor conductance						
G_{fe}	Core conductance						
G	Rotor & mag. circuit conductance						
$-B_2$	Rotor susceptance						
$-B_M$	Magnetizing susceptance						
$-B$	Rotor & magnetic circuit susceptance						
Y_2^2	Rotor & magnetizing circuit admittance						
R_g	Rotor & magnetic circuit resistance						
R_1	Stator resistance per phase						
R	Total resistance						
X_g	Rotor & magnetic circuit reactance						
X_1	Stator reactance						
X	Total reactance						
Z	Total impedance						
I_1	Stator current						
I_2	Rotor current						
	Stator power						
	Rotor power						
	Stator I^2R loss						
P_h	Core loss						
	Rotor I^2R loss						
P_f	Friction & Windage loss						
P_{SL}	Stray-Load loss						
	Total losses						
	Shaft power, in W						
	Efficiency in %						
	Power factor in %						
	Speed in r/min						
	Torque in N·m						

9.13 Form F2–Methods F, F1, C/F, E/F, and E1/F1 calculations

Serial No. ________________________ Model No. ________________________________

Type ________ Rating ___________ Voltage _________ Synchronous Speed _________ Phase __________ Frequency ___________

Before starting calculation, fill in following items, obtained from previous tests:
R_2 = ____(1)____ V = phase volts____(2)____ P'_{SL}__(3)___at I'_2 ___(4)____and n_S___(5)___also all the items below that are marked with an asterisk. (n_S = synchronous speed)

Assume a value of slip, s, corresponding to expected full-load speed for full-load point and proportional values for other loads. For motor operation, s is positive. For generator operation, s is negative. Numbers in ( ) represent item numbers.

Item	Description (Motoring)(Generating)		Source or Calculation
6	s	Slip in p.u.	Assume values for each load point
7	R_2/s	Effective rotor resistance	(7) = (1) / (6)
*8	X_2	Rotor reactance	From equivalent circuit, see 5.9
9	Z_2^2	Rotor impedance [Quantity squared]	$(9) = (7)^2 + (8)^2$
10	G_1	Rotor conductance	(10) = (7) / (9)
*11	G_{fe}	Core conductance	From equivalent circuit, see 5.9
12	G	Rotor & magnetic circuit conductance	(12) = (10) + (11)
13	$-B_2$	Rotor susceptance	(13) = (8) / (9)
*14	$-B_M$	Magnetizing susceptance	From equivalent circuit, see 5.9
15	$-B$	Rotor & magnetic circuit susceptance	(15) = (13) + (14)
16	Y_2^2	Rotor & magnetizing circuit admittance [Quantity squared]	$(16) = (12)^2 + (15)^2$
17	R_g	Rotor & magnetic circuit resistance	(17) = (12)/(16)
*18	R_1	Stator resistance per phase	From tests, see 5.9
19	R	Total resistance	(19) = (17) + (18)
20	X_g	Rotor & magnetic circuit reactance	(20) = (15) / (16)
*21	X_1	Stator reactance	From equivalent circuit, see 5.9
22	X	Total reactance	(22) = (20) + (21)
23	Z	Total impedance	(23) = square root of $[(19)^2 + (22)^2]$
24	I_1	Stator current	(24) = (2) / (23)
25	I_2	Rotor current	(25) = (24) / square root of [(9) × (16)]
26		Stator power	$(26) = 3 \times (24)^2 \times (19)$
27		Rotor power	$(27) = 3 \times (25)^2 \times (7)$
28		Stator I^2R loss	$(28) = 3 \times (24)^2 \times (18)$
29	P_h	Core loss	$(29) = 3 \times (24)^2 \times (11) / (16)$
30		Rotor I^2R loss	(30) = (6) × (27)
*31	P_f	Friction & Windage loss	From tests, see 9.14
32	P_{SL}	Stray-Load loss	$(32) = (3) \times [(25) / (4)]^2$
33		Total losses	(33) = (28) + (29) + (30) + (31) + (32)
34		Shaft power, in W	(34) = (26) – (33)
35		Efficiency in %	For Motoring: (35) = 100 × (34) / (26) For Generating: (35) = 100 × (26) / (34)
36		Power factor in %	(36) = 100 × (19) / (23)
37		Speed in r/min	(37) =(5) × [1–(6)]
38		Torque in N·m	(38) = 9.549 × (34) / (37)

9.14 Test and equivalent circuit results

Machine ______________________________ Serial No. _____________________ Model No. _____________________
Type _________ Rating _________ Voltage _________ Synchronous Speed _________ Frequency ________ Phases ______

Summary of Tests

No Load	
Line Current, I_o, in A	Stator Power, P_o, in W

Impedance Data by Method ____ of 5.9.1			
Frequency Hz	Line Volts V_L	Line Current, I, in A	Stator Power, P, in W

Constants and Summary of Equivalent Circuit Parameters

V_1 ___________ volts per phase
R_1 ___________ ohms
R_2 ___________ ohms
R_{fe} ___________ ohms
X_1 ___________ ohms
X_2 ___________ ohms
$(X_1 + X_2)$ _______ ohms
B_M ___________ siemens
G_{fe} ___________ siemens
P_f ___________ # watts See 5.5.4.
P_h ___________ #watts See 5.5.5.
P_{SL} ___________ # * watts at I_2 = ______amperes
N_S ___________ r/min

*See 5.7.2, 5.7.3, or 5.7.4.

When used in Method F, F1, C/F, E/F, or E1/F1 tests, these quantities are for the total machine and all others are per phase.

Annex A

(informative)

Bibliography

[B1] 10 CFR Part 431, Department of Energy, Office of Energy Efficiency and Renewable Energy, "Energy Efficiency Program for Certain Commercial and Industrial Equipment: Test Procedures, Labeling, and Certification Requirements, for Electric Motors, Final Rule," *Federal Register*, Vol. 64, No. 192, pp 54114-54172, October 5, 1999.

[B2] API Std 541, 4th Edition: Form-Wound Squirrel Cage Induction Motors—500 Horsepower and Larger, 2003.

[B3] IEC 60034-9: Rotating Electrical Machines—Part 9: Noise Limits, 1997.

[B4] IEC 60034-14: Rotating Electrical Machines—Part 14: Mechanical vibration of certain machines with shaft heights 56mm and higher—Measurement, evaluation and limits of vibration, 1996.

[B5] IEEE Std 1™-1986, IEEE Standard General Principles for Temperature Limits in the Rating of Electric Equipment and for the Evaluation of Electrical Insulation.

[B6] IEEE Std 4™-1995 Standard Techniques for High-Voltage Testing.

[B7] NEMA MG-1-2003, Motors and Generators.

[B8] NIST Handbook 150-10, Efficiency of Electric Motors, (EEM).

Annex B

(informative)

Typical report of test form for routine tests

Name of Manufacturer___________________________________

Address of Manufacturer _________________________________

____

Purchaser ____

Date of Test ____

Manufacturer’s Order No. _____________________________

Purchaser’s Order No. ________________________________

Nameplate Data

Rated hp/kW	Service Factor	Rated Speed r/min	Phase	Frequency Hz	Volts	Amperes

Type	Frame	(Temp Rise by method Indicated) (Ambient temp and Insulation Class)	Time Rating	Design Letter	Code Letter for Locked kVA/hp

Test Characteristics

Serial No.	No Load					Locked Rotor					Wound Rotor Open-Circuit Voltage	High Potential Test Voltage	Stator Winding Resistance Between Terminals	
	Volts	Frequency Hz	Speed r/min	Amperes	Kilowatts*	Volts	Frequency Hz	Amperes	Kilowatts*				Ohms	Temp in ˚C

*If measured, optional.

Notes:

Data on test from __________machine
(this or duplicate)

Approved by __________________________Date_______________

Annex C

(informative)

Typical report of test form

Name of Manufacturer ______________________________ Manufacturer's Order No. ______________________________

Address of Manufacturer ______________________________ Date of Test ______________________________

Serial No. ______________________________ Purchaser's Order No. ______________________________

Model Number ______________________________ Purchaser ______________________________

Nameplate Rating

Rated hp/kW	Service Factor	Rated Speed r/min	Phase	Frequency Hz	Volts	Amperes	Type	Frame

Temperature Rise

Conditions of Test				Temperature Rise__________°C					
				Stator		Rotor			
					Windings		Windings		
Hours Run	Line Volts	Line Amperes	Cooling Air, °C		*By Method		*By Method		

Characteristics

Rated Slip percent	No-Load Line Current, amperes	Secondary Volts at Standstill	Secondary Amperes per Ring at Rated Load	Resistance at 25 °C (between lines), ohms
				Prim
				Sec

Torque and Starting Torque

Break-Down Torque in_________#	Locked-Rotor Torque in________ #	Starting Current Amperes (locked rotor)
with___% volts applied	with____% volts applied	with____% volts applied

High Potential Tests

Volts ac for________ Sec.	
Stator	Rotor

Efficiencies and Power Factor

Efficiency, Percent			Power Factor, Percent		
Rated Load	75% Load	50% Load	Rated Load	75% Load	50% Load

*Indicate method as: Thermometer, Thermocouple, Resistance, or Embedded Detector. #Indicate units: N·m or lbf·ft

Notes:

Data on test from _______________ machine Approved by __________________________________Date
(this or duplicate)

Annex D

(informative)

Units of measure

D.1 Units of measure

This standard uses metric units of measure in accordance with IEEE standard policy. However, this standard can be used when the units of measure are horsepower, hp, for shaft power, pound-force·feet, lbf·ft, for the torque(s) and pound·feet^2, lb·ft^2, for inertia. The areas in the specification that need to be modified when using these customary units and the specific modifications required are covered in D.1.1 through D.1.5.

D.1.1 Mechanical power

D.1.1.1 Load test

The mechanical power in the load test as calculated in 5.6.1.1 is in watts. With the shaft torque, T, being measured in lbf·ft instead of N·m, the k_2 factor in Equation (10) is 7.043 instead of 9.549. See D.1.2.1.

D.1.1.2 Output power

The output power of a motor (input power of a generator) can be presented in horsepower by simple conversion of the calculated *corrected stator power* of the test forms. This power value as calculated is in watts. Divide this calculated power by 745.7 and the resulting number is the output power in hp. See Table D.1.

D.1.2 Torque

D.1.2.1 Shaft torque

The shaft torque used in the mechanical power calculation of D.1.1.1 is obtained from Equation (11), which starts with the measured shaft torque and applies a dynamometer correction factor, if this correction is needed. Equation (11) is valid for either unit of torque measure as long as all torques values use the same units of measure. Using mixed units of measure will always give wrong results and will invalidate the test.

D.1.2.2 Dynamometer correction

The dynamometer correction is calculated as in 5.6.1.2 using Equation (12). The dynamometer correction torque, in lbf·ft, T_D, is calculated using Equation (12) with k_2 equal to 7.043 and with T_A measured in lbf·ft.

D.1.2.3 Locked-rotor torque

See 7.2.2. The locked-rotor torque can be calculated using Equation (77). Change the value of factor k_2 to 7.043 and the result of solving Equation (77) will be the maximum locked-rotor torque in lbf·ft.

D.1.2.4 Speed-torque curve—Method 1

See 7.3.2.1. The torque at each load point can be calculated using Equation (78). Change the value of factor k_2 to 7.043 and the result of solving Equation (78) will be the torque in lbf·ft.

D.1.2.5 Speed-torque curve—Method 2

See 7.3.2.2. As in D.1.2.5, the torque at each load point can be calculated using Equation (79). However, the moment of inertia must be in lb·ft^2. With this and changing the value of factor k_2 to 7.043, the result of solving Equation (79) will be the torque in lbf·ft.

D.1.2.6 Speed-torque curve–Method 3

See 7.3.2.3. The torque at each load point can be calculated using Equation (80). Change the value of factor k_2 to 7.043 and use values of motor friction and windage torque, T_{fw}, in lbf·ft. Solve Equation (80) for each speed point and the resulting values will be the torque, T, measured in lbf·ft.

D.1.3 Test forms

When using customary units, the test forms of Clause 9. should be modified to show the correct units of measure, 1bf·ft for torque and hp for shaft power, to add additional lines to show shaft power in hp and to show the correct k_2 factor in applicable calculations. The changes needed are shown in Table D.1.

Table D.1—Form changes required

Subclause	Form I.D.	Units are:	Item No.	Add line after No.	Add on new line	Calculation
9.2, 9.3	A, A1	1bf·ft	14, 15, 16	—	—	—
		—	17	—	—	* (17) = (16) × (13) / 7.043
		—	—	26	Shaft Power, in hp	= (17) / 745.7
9.4, 9.5	B, B2	1bf·ft		—	—	—
		—		—	—	* (27) = (26) × (12) / 7.043
		—		43	Shaft Power, in hp	= (41) / 745.7
9.6, 9.7	B1, B1-2	1bf·ft			—	—
		—	23		—	* (23) = (22) × (8) / 7.043
		—	—	39	Shaft Power, in hp	= (37) / 745.7
9.8, 9.9	C, C2	—	—	98	Shaft Power, in hp	= (97) / 745.7
		—	—	107	Shaft Power, in hp	= (106) / 745.7
9.10, 9.11	E, E2	—	—	28	Shaft Power, in hp	= (26) / 745.7
9.12, 9.13	F, F1	—	—	38	Shaft Power, in hp	= (34) / 745.7

* These calculations are basically unchanged, only the constant has changed because of the use of 1bf·ft units for the shaft torque.

NOTE—The “new line” for the test forms shown in Table D.1, is for recording the shaft power in horsepower. These lines are introduced at the bottom of the forms so the Item Numbers that show calculations are not compromised. On the actual test form, this new line could appear directly after the existing “Shaft Power, in W” listing, if desired.

D.1.4 Assumed stray-load loss

The stray-load loss to be used with machines being tested by Efficiency Test Methods E1, F1 or E1/F1 is selected from Table D.2 based on the rated horsepower.

Table D.2—Assumed values for stray-load loss

Machine rating In hp	Stray-load loss percent of rated load
1–125	1.8%
126–500	1.5%
501–2499	1.2%
2500 and greater	0.9%

The value of stray-load loss at rated load [P'_{SL} in Equation (22)], in watts, is equal to the product of the percent value of stray-load loss in Table D.2, the rated hp, and the conversion factor 745.7 divided by 100.

D.1.5 Resistance reading at shutdown

Table D.3 shows the maximum permitted time between shutting off the power on the temperature test and obtaining the first stator resistance reading. The maximum delay is selected from Table D.3 based on the machine horsepower rating.

Table D.3—Maximum time delay in resistance measurements

Machine rating in hp	Time delay after switching off power (seconds)
50 or less	30
Above 50 to 200	90
Above 200	120