

IEEE Standard Test Procedure for Polyphase Induction Motors and Generators

IEEE Power and Energy Society

Sponsored by the
Electric Machinery Committee

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IEEE Standard Test Procedure for Polyphase Induction Motors and Generators

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Electric Machinery Committee
of the
IEEE Power and Energy Society

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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, IEEE 112™, induction, machines, motors, polyphase

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Introduction

This introduction is not part of IEEE Std 112-2017, IEEE Standard Test Procedure for Polyphase Induction Motors and Generators.

This standard provides the basic test procedures 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 and test techniques, 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. 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.

Major additions to this revision include load testing by the superposition equivalent loading method. This is an alternative temperature test method that provides advantages for testing large machines that exceed test equipment and power supply limitations. Annex E has been added to this standard to explain the determination of total error.

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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. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

ANSI/IEEE Std 120™, IEEE Master Test Guide for Electrical Measurements in Power Circuits.^{1, 2, 3}

IEEE Std 43™, IEEE Recommended Practice for Testing Insulation Resistance of Rotating Machinery.

IEEE Std 118™, IEEE Standard Test Code for Resistance Measurement.

IEEE Std 119™, IEEE Recommended Practice for General Principles of Temperature Measurement as Applied to Electrical Apparatus.⁴

NEMA MG 1, Motors and Generators.⁵

3. General

3.1 Power supply

3.1.1 Selection

Because the performance of an induction machine depends 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).

$$\text{THD} = \frac{\sqrt{E^2 - E_1^2}}{E_1} \quad (1)$$

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 volts (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.

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⁴ IEEE Std 118-1978 and IEEE Std 119-1974 have been withdrawn; however, copies can be obtained from the Institute of Electrical and Electronics Engineers (<http://standards.ieee.org/>).

⁵ NEMA publications are available from the National Electrical Manufacturers Association (<http://www.nema.org/>).

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 $100\% \times \left(\frac{5}{215} \right) = 2.3\%$.

3.1.4 Frequency

For general testing, the average frequency shall be within $\pm 0.5\%$ 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 average frequency shall be within $\pm 0.1\%$ of the specified test value.

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 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. 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 (see 8.3) 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, unless stated otherwise, 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, the following is necessary:

- 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 s after test voltage is reached.

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 6.2.2.

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 shall 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.

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

3.4 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.

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, include the following:

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

Since a component of 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 include the following:

- 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 $\pm 0.5\%$ of full scale for general testing or no greater than $\pm 0.2\%$ of full scale when the test results are for use with Efficiency Test Method A or B.

Additionally, for Efficiency Test Methods A and B, the operating range for the instruments shall be selected such that at rated full-load of the motor under test:

- The total error for current measurements shall not exceed $\pm 0.5\%$ of the full-load reading (including all errors from the ammeter and CTs).
- The total error for power measurements shall not exceed $\pm 1.0\%$ of the full-load reading (including all errors from the wattmeter, CTs, and VTs).

See Annex E for information on determining the total error of measurements.

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.

4.1.3 Instrument transformers

When 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 $\pm 0.5\%$ for general testing, or not greater than $\pm 0.3\%$ 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 $\pm 0.2\%$ of full scale when the test results are for use with Efficiency Test Method B.

4.1.4 Voltage

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 of the voltages 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. 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.

4.1.7 Frequency

The instrument used to measure frequency shall have an accuracy of $\pm 0.05\%$ of reading.

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 $\pm 0.2\%$ 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 and IEEE Std 119 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. An in-line torque transducer may be used to provide a direct measurement of torque at the test machine shaft. 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.⁶

The errors of the instrumentation used to measure mechanical torque shall not be greater than $\pm 0.2\%$ of full scale. Additionally, for Efficiency Test Methods A and B, the operating range for the instrumentation shall be selected such that at rated full-load of the motor under test, the total error for torque measurements shall not exceed $\pm 0.7\%$ of the reading, which shall include all errors from all sources (load cell, torque arm length, etc.). The error of the instrumentation can be validated by calibration as a system or by calculation from the square root of the sum of the squares of the individual instrument errors. See Annex E for information on determining the total error of measurements.

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.

For measurements for which the speed is less than or equal to 1800 r/min, the total error of the instrumentation used for speed or slip measurements shall not exceed ± 1.0 r/min.

For measurements for which the speed is greater than 1800 r/min, the total error:

- For speed measurements shall not exceed $\pm(0.1 \text{ r/min} + 0.05\% \text{ of the reading})$
- For slip measurements shall not exceed a value equivalent to $\pm(0.1 \text{ r/min} + 0.05\% \text{ of } [\text{synchronous r/min} - \text{slip r/min}])$

⁶ Notes in text, tables, and figures of a standard are given for information only and do not contain requirements needed to implement this standard.

4.4 Temperature

4.4.1 Methods of measuring temperatures

4.4.1.1 Overview

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

- a) Local temperature detector
- b) Embedded detector
- c) Winding resistance

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 and IEEE Std 1TM-1986 [B5].⁷

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 the following:

- Thermocouples
- Small resistance thermometers
- 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 on the following parts:

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

The detectors are frequently installed as permanent parts of a machine and are available for use during tests.

⁷ The numbers in brackets correspond to those of the bibliography in Annex A.

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 ensure 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 5.3.2.

4.4.1.5 Ambient temperature

The procedure of IEEE Std 119 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

WARNING

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

5.1 Overview

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.

5.2 Types of losses

The losses of an induction machine include the following:

- Stator I^2R loss, see 5.3
- Rotor I^2R loss, see 5.4
- Friction and windage loss, see 5.6.5
- Core loss, see 5.6.6
- Stray-load loss, see 5.8
- Brush-contact loss, see 5.11

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

- Shaft power, see 5.7.2.2
- Dynamometer correction, see 5.7.2.3
- Equivalent circuit, see 5.10
- Temperature test, see 5.9

5.3 Stator I^2R loss

5.3.1 Overview

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

$$P_{SIR} = 1.5I^2R = 3I^2R_l \quad (2)$$

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 5.3.2)
 R_l is the per phase dc resistance, in ohms (see 5.10)

5.3.2 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).

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

where

- R_a is the known value of winding resistance, in ohms, at temperature t_a
 t_a is the temperature, in degrees Celsius, of winding when the resistance R_a was measured
 t_b is the temperature, in degrees Celsius, 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 6.4.3.4.

5.4 Rotor I^2R loss

5.4.1 Overview

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:

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

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

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).

5.4.2 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)].

$$\text{slip speed} = n_s - n_t \quad (6)$$

where

$$n_s = 120 \times \frac{f}{p} \quad (7)$$

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:

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

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 by 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.

5.4.3 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.

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

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 degrees Celsius, see 3.3.2
- t_t is the observed stator winding temperature during load test, in degrees Celsius
- 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)

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

NOTE 2—The values for t_s and t_t is based on the same method of measurement of temperature, see 5.3.2.

5.5 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 3.3.2.

5.6 No-load test

5.6.1 Overview

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 record temperature, voltage, current, and power input at rated frequency. Test at three or more values of voltages between 125% and 75% of the nominal voltage, with a point near 100% rated voltage, and three or more values of voltage between 50% of rated voltage and 20% of rated voltage or to that point where further voltage reduction increases the current.

5.6.2 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.

5.6.3 No-load current

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

5.6.4 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.

5.6.5 Friction and windage loss

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. 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.

5.6.6 Core loss

The core loss, P_h , at each test voltage is obtained by subtracting the value of friction and windage loss (determined in 5.6.5) from the input power minus stator I^2R loss (determined in 5.6.5). A plot of core loss versus voltage can be constructed for use in determining the core loss at any desired voltage.

5.7 Load test

5.7.1 Overview

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.

The stator winding resistance for each load point can be estimated by comparing the temperature measured by an embedded temperature detector, a temperature sensor located on the stator coil end, or the air outlet temperature, with corresponding temperature 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 item c) in 3.3.2.

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 5.7.2.
- Direct loading without torque measurement. See 5.7.3.
- Duplicate machine loading. See 5.7.4.

5.7.2 Dynamometer loading

5.7.2.1 Overview

For this test, the machine is loaded by means of a mechanical brake or dynamometer (see 4.3.1) and tested as described in 5.7.

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.

5.7.2.2 Mechanical power

The shaft power, in watts, 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 5.7.2.3.

$$P = \frac{2\pi n_i T}{60} = \frac{n_i T}{k_2} \quad (10)$$

where

- P is shaft power, in watts
- n_i is the measured speed or the speed calculated using measured slip, in r/min
- k_2 is 9.549 for torque in Newton·meters
- T is the torque, in Newton·meters⁸. See Equation (11) if dynamometer correction is required

$$T = T_i \pm T_D \quad (11)$$

where

- T_i is a measured torque, in Newton·meters
- T_D is the dynamometer correction from Equation (12), in Newton·meters

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.

⁸ For other units of measure, see Annex D.

5.7.2.3 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 5.6) 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). In the following, *Test A* refers to the test with the motor coupled to the dynamometer, and *Test B* to the motor uncoupled.

$$T_D = k_2 \times \frac{P_A - P_B}{n_A} - T_A \quad (12)$$

where

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

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

and

- T_D is the correction to be applied the load torque before performing the power calculation of 5.7.2.2
- P_{inA} is input power, in watts, 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 watts, during Test A
- s_A is slip, in p.u., during Test A
- T_A is the torque, in Newton·meters, 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 watts, during a no-load test at rated voltage (Test B)
- P_{SIRB} is the stator I^2R loss, in watts, during a no-load test at rated voltage (Test B)
- P_h is the core loss, in watts, during a no-load test at rated voltage
- k_2 is 9.549 for torque in Newton·meters

5.7.3 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 5.7. A reading of torque at each load point is not required.

5.7.4 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.

5.8 Stray-load loss

5.8.1 Introduction

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.

5.8.2 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).

5.8.3 Direct measurement

5.8.4 Introduction

Direct measurement of the stray-load loss is used in Efficiency Test 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.

5.8.4.1 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 5.8.4.2 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, current, and the winding temperature.

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

where

- I_t is the value of stator winding current, in amperes, during stray-load loss test
- I_0 is the value of no-load current, in amperes (see 5.6.3)

I is the operating value of stator line current, in amperes, for which stray-load loss is to be determined

5.8.4.2 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 5.8.4.1. The magnitude of the currents should 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 5.8.4.1 and 5.8.4.2 make it imperative that phase angle error corrections be applied to all wattmeter readings. Refer to IEEE Std 120.

5.8.4.3 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).

$$P_{SL} = P_{SLs} + P_{SLr} \quad (16)$$

where

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

5.8.4.4 Smoothing the test data

Smooth the raw data— $(P_r - P_m)$, P_s and P_{rr} —from the tests of 5.8.4.1 and 5.8.4.2 using a series of three regression analyses. Each regression analysis is of the log of a test power versus the log of the test current. The result of these analyses is shown in Equation (17) through Equation (19).

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

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

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

where

- A_1 is a y intercept on a log-log plot (a constant)
- A_2 is a y intercept on a log-log plot (a constant)
- A_3 is a y intercept on a log-log plot (a constant)
- N_1 is a slope on a log-log plot (approximately 2)
- N_2 is a slope on a log-log plot (approximately 2)
- N_3 is a slope on a log-log plot (approximately 2)
- I_t is the observed line current during the stray-load 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.

5.8.4.5 Calculating stray-load loss at a specified point

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

$$I'_2 = \sqrt{I^2 - I_0^2} \quad (20)$$

where

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

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):

$$P'_{SL} = A_1 (I'_2)^{N_1} + 2A_2 (I'_2)^{N_2} - A_3 (I'_2)^{N_3} - 3 \times (I'_2)^2 \times (2R_{ls} - R_{lr}) \quad (21)$$

where

- P'_{SL} is the value of stray-load loss, in watts, 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 5.8.4.1)
- R_{1r} is the stator resistance per phase, in ohms, during the reverse rotation test at test temperature (see 5.8.4.2)

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 amperes, for which stray-load loss is to be determined
- I_0 is the value of no-load current, in amperes

5.8.5 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).

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

If six load points are used, the accuracy can be improved by plotting stray-load loss versus stator winding current squared and by following a smoothing procedure similar to that used in 5.8.4.4. The stator $I^2 R$ in Equation (24) is at the temperature during the test.

5.8.6 Assumed stray-load loss

An assumed value of stray-load loss is used with Efficiency Test Methods E1, F1, and E1/F1 (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, 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.

Table 2—Assumed values for stray-load loss

Machine rating (kW)	Stray-load loss percent of rated load
0.7457 to 90	1.8%
91 to 375	1.5%
376 to 1850	1.2%
1851 and greater	0.9%

5.9 Temperature test

5.9.1 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 5.9.2 through 5.9.5 are guides for the test and for the treatment of the data.

5.9.2 General instructions

5.9.2.1 Introduction

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.

5.9.2.2 Measuring devices

Temperature measuring devices shall be in accordance with IEEE Std 119. 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.

5.9.3 Loading method

5.9.3.1 Introduction

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

- a) Actual loading method
- b) Superposition equivalent loading method
- c) Primary-superposed equivalent loading method
- d) Forward stall equivalent loading method

NOTE—The methods described below in 5.9.3.3 (superposition equivalent loading method), 5.9.3.4 (primary-superposed equivalent loading method), and 5.9.3.5 (forward stall equivalent loading method) reproduce a close approximation of the thermal conditions of the machines under rated conditions. To avoid misunderstandings, the use of these methods should be discussed and adopted by agreement between the manufacturer and the purchaser when the temperature-rise measurement results achieved from these tests are to be taken as the basis for the evaluation of machine's temperature rise at rated load.

5.9.3.2 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.

5.9.3.3 Superposition equivalent loading method

5.9.3.3.1 Introduction

The superposition equivalent loading method is an alternative temperature test method that provides advantages for testing large machines that exceed test equipment and power supply limitations, when the machine can be partly loaded. The test method is one in which the temperature rise of the machine at rated conditions is determined by applying the principles of linear superposition to the temperature rises obtained from a series of tests.

The principles of linear superposition can be applied to various combinations of tests selected according to the test equipment and power supply available. The three methods identified in this standard are as follows:

- a) Method of reduced voltage and rated current
- b) Method of rated voltage and reduced current
- c) Method of reduced voltage and reduced current

5.9.3.3.2 Method of reduced voltage and rated current

For the method of reduced voltage and rated current, a temperature test at rated current in the machine is obtained by operation at a combination of reduced voltage and reduced load at rated frequency.

With the reduced voltage on the machine, the stator iron losses are lower than under the actual loading conditions with rated voltage. To compensate for this difference, the test is supplemented by two no-load

temperature tests at rated frequency, one at rated voltage and one at the reduced voltage used during the rated current test.

A series of three tests are performed as follows:

Subtest 1 is performed at no load, rated voltage, and rated frequency. This provides the stator winding temperature rise Δt_1 due to stator winding losses at rated no-load stator current, no-load core losses at rated voltage, and the full friction and windage losses.

Subtest 2 is performed at a combination of reduced voltage and reduced load at rated frequency such that the line current is equal to the rated current. The applied voltage at rated frequency shall be as high as practical using the available equipment. This subtest provides the stator winding temperature rise Δt_2 due to the stator losses at rated stator current, rotor losses at a quasi-rated rotor current, core losses at reduced voltage, and full friction and windage losses.

Subtest 3 is performed at no load at rated frequency at the same reduced voltage as in subtest 2. This subtest provides the stator winding temperature rise Δt_3 due to stator losses at a reduced level of no-load stator current, no-load core losses at reduced voltage, and full friction and windage losses.

For each of the subtests 1, 2, and 3, the voltage, frequency, current, input power, and stator winding resistance and temperature from embedded temperature detectors (when available) are measured.

The temperature rise by embedded temperature detector for each of the subtests shall be the total temperature of the highest reading embedded temperature detector minus the ambient temperature. The temperature rise by resistance for each of the subtests shall be the temperature of the stator winding determined from the resistance measurement minus the ambient temperature.

The temperature rise at rated voltage and rated stator current can be determined from the temperature rises measured for the three subtests as depicted in Figure 1. It is assumed that the machine can be represented by a linear thermal model such that for any level of voltage, the temperature rise of the stator winding varies linearly as a function of the I^2R losses in the stator winding. With subtests 2 and 3 performed at the same reduced voltage for rated frequency, the values of Δt_2 and Δt_3 are plotted against the respective value of stator winding losses (P_{SIR2} and P_{SIR3} according to 5.3) and a straight line is constructed between the two values. These points are labeled as points 2 and 3, respectively, in Figure 1. The slope of the line between the points 2 and 3 represents the rate of change of the temperature rise with the stator winding loss. The temperature rise Δt_1 at the value of the stator winding loss P_{SIR1} in subtest 1 is added to the plot as point 1 in Figure 1. This point corresponds to a point on the thermal characteristic corresponding to the operation at rated voltage. A linear line parallel to the line between points 2 and 3 is drawn through the point at 1 and extended to a value corresponding to the temperature rise at the value of stator winding loss corresponding to rated stator current, indicated as point 4 in Figure 1. This value of temperature rise Δt_4 is taken to be the temperature rise at rated voltage and rated stator current.