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IEEE Standard Test Procedure for Single-Phase Induction Motors

IEEE Industry Applications Society

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Electric Machines Committee

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Electric Machines Committee
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IEEE Industry Applications Society

Approved 30 September 2010

IEEE-SA Standards Board

Abstract: Instructions for conducting and reporting the more generally applicable and acceptable test to determine the performance characteristics of single-phase induction motors are covered in this standard.

Keywords: efficiency, IEEE 114, motor test procedure, single-phase induction motors, speed-torque characteristic

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Introduction

This introduction is not part of IEEE Std 114-2010, IEEE Standard Test Procedure for Single-Phase Induction Motors.

This introduction provides some background on the rationale used to develop this standard and is meant to aid in the understanding and usage of this document.

This standard describes laboratory tests conducted to evaluate the performance of certain single-phase induction motors. It is intended for the following:

- Individuals or organizations that use electric motors and purchase electric motors from manufacturers.
- Individuals or organizations that acquire electric motors for resale to other individuals or organizations.
- Individuals or organizations that influence how electric motors are purchased from manufacturers.
- Manufacturers interested in providing high-quality electric motors to the consumer.

This standard is designed to help organizations and individuals:

- Incorporate quality considerations during the design, evaluation, selection, and acceptance of single-phase induction motors for operational use.
- Determine how single-phase induction motors should be evaluated, tested, and accepted for delivery to end users.

This standard is intended to satisfy the following objectives:

a) Promote consistency among electric motor manufacturers in the performance evaluation of single-phase induction motors.
b) Provide useful practices for evaluating performance during the design of electric motors.
c) Provide useful practices for evaluating and qualifying manufacturer capabilities to meet user requirements.
d) Provide useful practices for evaluating and qualifying manufactured electric motors.
e) Assist individuals or organizations judging the quality of single-phase induction motors delivered to end users.

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1. Overview

This standard test procedure is divided into 11 Clauses. This overview as well as the scope and purpose of this standard test procedure are presented in Clause 1. References to other standards that are useful in applying this standard test procedure as provided in Clause 2. This standard test procedure covers a broad range of basic models of single-phase induction motors; common types of single-phase motors and the tests that are applicable to each are specified in Clause 3. Requirements for test instrumentation and other general testing facilities are presented in Clause 4. General procedures for electrical, mechanical and temperature measurements are presented in Clause 5. General test procedures and safety requirements are presented in Clause 6. A general discussion of loss is presented in Clause 7. Test methods for determination of motor efficiency and power factor are presented in Clause 8. Methods for determination of other performance are presented in Clause 9. Temperature tests are presented in Clause 10. Miscellaneous tests are described in Clause 11. Typical forms for the reporting the results of routine test, complete test, and a determination of efficiency are provided in Annex A. Bibliographic references are provided in Annex B.

1.1 Scope

This standard covers instructions for conducting and reporting the more generally applicable and acceptable tests to determine the performance characteristics of single-phase induction motors. It is not intended that this standard shall cover all possible tests used in production or tests of a research nature. The standard shall not be interpreted as requiring the making of any or all of the tests described herein in any given transaction.

1.2 Purpose

This standard is intended to satisfy the following objectives:

a) Promote consistency between electric motor manufacturers regarding the performance evaluation of single-phase induction motors.

b) Provide useful practices on evaluating performance during the design of electric motors.

c) Provide useful practices on evaluating and qualifying manufacturer capabilities to meet user requirements.

d) Provide useful practices for evaluating and qualifying manufactured electric motors.

e) Assist individuals or organizations judging the quality of single-phase induction motors delivered to end users.

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/NEMA MG 1-2006 (Rev 1 – 2007), Motors and Generators.[1]

IEEE Std 1™-2000, IEEE Recommended Practice — General Principles for Temperature Limits in the Rating of Electric Equipment and for the Evaluation of Electrical Insulation.[2, 3]

IEEE Std 43™ -2000 (R2006), IEEE Recommended Practice for Testing Insulation Resistance of Rotating Machinery.

IEEE Std 85™ -1973, IEEE Test Procedure for Airborne Sound Measurements on Rotating Electric Machinery.[4]

IEEE Std 118™-1978, IEEE Standard Test Code for Resistance Measurement.

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

IEEE Std 120™ -1989 (R2007), IEEE Master Test Guide for Electrical Measurements in Power Circuits.

3. General tests

Single-phase induction motors are normally given a routine test. A routine test includes measurement of input power and input current at no-load, measurement of input current with locked rotor, and a high potential test. Measurements of input power and input current at no-load and with locked rotor are

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[4] IEEE Std 85-1973, IEEE Std 118-1973 and IEEE Std 119-1974 have 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/).

obtained at rated voltage and frequency. A typical form for reporting the results of a routine test is shown in Form 1, Annex A.

Additional tests may be conducted for the determination of efficiency, power factor, starting torque, pull-up torque, breakdown torque, rated-load slip, and load temperature rise. A typical form for reporting these additional test data is shown in Form 2, Annex A. Tests to determine locked-rotor temperature rise, speed-torque characteristics, noise, and vibration may also be conducted.

3.1 Schedule of tests

Common types of single-phase induction motors are listed in Table 1 together with tests applicable to each motor type. Test types in Table 1 correspond to the following as defined in IEEE 100™[B3].

a) Locked-rotor current
b) Locked-rotor torque
c) Pull-up torque
d) Switching torque
e) Pull-in torque
f) Breakdown torque
g) Pull-out torque
h) Speed
i) Power factor
j) Efficiency
k) Temperature rise

Tests for speed, power factor, efficiency, and temperature rise are usually conducted at rated load; however, these tests may be conducted at any load, as required.

Table 1—Test parameter applicable to single-phase motors

	Locked rotor current	Locked rotor torque	Pull-up torque	Switching torque	Pull-in torque	Breakdown torque	Pull-out torque	Speed	Power factor	Efficiency	Temperature rise
Capacitor (permanent split)	X	X	X			X		X	X	X	X
Capacitor (two-value)	X	X	X	X		X		X	X	X	X
Capacitor - start	X	X	X	X		X		X	X	X	X
Split-phase	X	X	X	X		X		X	X	X	X
Repulsion	X	X				X		X	X	X	X
Repulsion-induction	X	X	X			X		X	X	X	X
Repulsion-start-induction	X	X	X	X		X	X	X	X	X	X

3.2 Tests with load

Tests with load are made for the purpose of determining efficiency, power factor, speed, and temperature rise.[5] For all tests with load, the motor shall be properly aligned and securely fastened. For load tests, other than efficiency, the motor temperature rise shall be between 50% and 100% of temperature rise at rated load. The usual procedure is to take readings at higher loads first and follow with readings at lower loads.

3.3 Tests with rotor locked

It should be recognized that the testing of induction motors under locked-rotor conditions involves high mechanical stresses and high rates of heating. Therefore, the following precautions are necessary:

a) The mechanical means of locking the rotor must be of adequate strength to prevent possible injury to personnel or damage to equipment.

b) The direction of rotation must be determined prior to test so that methods of fastening and of measuring torque can be properly applied.

c) The motor is at approximately ambient temperature before the test is started.

Current and torque readings should be taken as quickly as possible after voltage is applied. The period of time between application of voltage and current and torque readings shall not exceed 5 s. The motor temperature should not exceed the rated temperature rise plus 40 °C.

3.4 Precautions

Inasmuch as the performance of a single-phase motor depends not only upon the voltage and frequency, but also upon the wave shape of the voltage, correct data can be obtained only by careful measurement and the use of a suitable source of power (see 4.2).

CAUTION

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

4. Testing facilities

4.1 Instrument selection

Calibrated, high-accuracy instrumentation and accessory equipment shall be used. Either analog or digital type instruments may be used in testing. Factors affecting accuracy, particularly with non-electronic analog instruments, are shown as follows:

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

---

[5] Temperature rise is measured winding temperature at rated load minus the measured ambient temperature.

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

At the time of testing, the indicating instruments shall bear record of calibration, within the previous 12 months, indicating limits of the error no greater than ± 0.2% of full scale for determination of efficiency. The instrument error for other motor performance testing shall be no greater than ± 0.5% of full scale. When several instruments are connected in the circuit simultaneously, additional corrections of the instrument indication may be required.

Electronic instruments are generally more versatile and have much higher impedances than passive (non-electronic) instruments. Higher input impedance reduces the need to make corrections for the current drawn by the instrument. However, high-input impedance instruments are more susceptible to noise.

Common sources of noise are as follows:

a) Inductive or electrostatic coupling of signal leads to power systems;
b) Common impedance coupling or ground loops;
c) Inadequate common mode rejection; and
d) Conducted interference from the power line.

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

Instrument calibration requirements are similar to those of non-electronic instruments. 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.[6]

4.1.1 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 use of instrument transformers shall be avoided if possible (see IEEE Std 120-1989).

The errors of the instrument transformers used shall not be greater the 0.3%.

4.2 Power supply

The power supply voltage shall closely approach a sinusoidal waveform. The voltage waveform deviation factor, as defined in IEEE 100[B3], shall not exceed 10%. The frequency shall be maintained within ± 0.5% of the value required for the test being conducted, unless otherwise specified. Any departure from the assumed frequency directly affects the efficiency. For a determination of efficiency, the average frequency shall be within ± 0.1% of the required test value.

4.2.1 Frequency stability

Rapid changes in frequency cannot be tolerated in input-output tests because such changes in frequency cause changes in speed and the variations are transmitted to the output-measuring device. Variations in frequency during a test shall not exceed 0.33% of the average frequency.

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[6] Information on references can be found in Clause 2.

5. Measurements

5.1 Electrical measurements

5.1.1 RMS quantities

All voltage and current measurements are rms values, unless otherwise indicated.

5.1.2 Voltage

The line voltage shall be measured with signal leads connected to the motor terminals whenever possible. If local conditions will not permit such connections, the error introduced shall be evaluated and the readings shall be corrected.

Means should be provided whereby the voltage can be adjusted to the desired value. This control can be effected by the use of a continuously variable transformer or autotransformer, by an induction regulator, by a controlled motor-generator set, or by solid state power synthesis.

5.1.3 Current

The line current shall be measured by an ammeter or current transducer. The preferred arrangement of meters is shown by the circuit diagram in Figure 1.

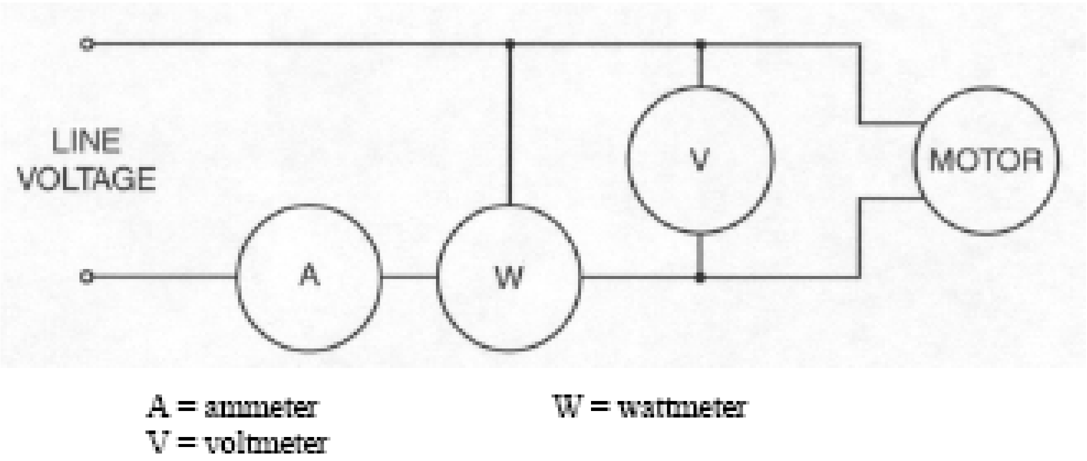

Figure 1—Preferred meter arrangement

The motor net current, I, is the true current input to the motor. It is obtained from the measured line current by subtracting the voltmeter and wattmeter shunt currents, and may be computed by using Equation (1):

$$I = \sqrt{I_A^2 - \frac{2P_W}{R_M} + \left(\frac{E}{R_M}\right)^2} \tag{1}$$

where

I_A is the measured line current (A);
I_A is the measured line current (A);
P_W is the power indicated by wattmeter (W);
E is the line voltage measured at the motor terminals (V);
R_M is the resistance of the voltmeter and wattmeter voltage coils in parallel (Ω).

Alternatively, the motor net current may be computed by using Equation (2):

$$I = I_A - \frac{P_W}{I_A R_M} \tag{2}$$

provided the condition $I_A > 7\frac{E}{R_M}$ holds.

If digital instruments are used, the motor current can be measured directly.

5.1.4 Power

A single-phase wattmeter or power transducer shall be used. The total watts read on the wattmeter, which shall be connected according to 6.1.1, shall be reduced by the amount of the power lost in the voltage circuit of the instruments unless a properly selected power transducer is used and the transducer loss is shown to be negligible.

5.1.5 Resistance

The procedures given in IEEE Std 118-1978 should be used to obtain dc resistance measurements of the stator.

5.1.5.1 Reference ambient temperature

All resistance measurements should be corrected to a reference ambient temperature of 25 °C.

5.1.5.1.1 Correction to a specified temperature

When the resistance of a winding has been determined by test at winding temperature t_t , the resistance may be corrected to a specified temperature t_s, as shown in Equation (3).

$$R_s = \frac{R_t(t_s + k)}{(t_t + k)} \tag{3}$$

where

R_t is the measured winding resistance, (Ω), at temperature tt;
t_s is the specified temperature for resistance correction (°C);
t_t is the measured temperature of the winding (°C);
k is a constant selected according to the wire type,
k is 234.5 for 100% International Annealed Copper Standard (IACS) conductivity copper
k is 224.8 for aluminum, based on a volume conductivity of 62%.

5.2 Mechanical measurements

5.2.1 Torque

The torque may be measured by dynamometer, with a rotating-shaft torque sensor, by stator reaction, or by measuring the acceleration with an inertia load.

5.2.1.1 Dynamometer

A dynamometer is a device for applying torque to the motor shaft. It is equipped with a means of indicating torque and speed, and is not limited to a cradle base construction.

In this method the motor is connected to a dynamometer usually by means of a flexible coupling. Bearing friction and coupling losses must be compensated for. A properly sized dynamometer should be used, such that the coupling, friction, and windage losses of the dynamometer measured at rated speed of the motor should not be greater than 15% of the rated output of the motor. The dynamometer should be sensitive to a change in torque of 0.1% of the rated torque.

5.2.1.1.1 Dynamometer correction

The dynamometer correction is a correction to the measured torque. In the case where dynamometer correction is required, the measured values of torque are corrected by adding a correction torque corresponding to the friction and windage loss associated with the dynamometer. Dynamometer correction is required if a load cell and a torque arm is used in torque measurement. If a torque transducer is directly connected to the shaft of the test motor or the stator reaction torque is measured then the dynamometer correction is not required.

The correction is calculated from measurements of the input power and torque with the motor running unloaded and coupled to the dynamometer and the input power measurement with the motor uncoupled from the dynamometer.

The following procedure of dynamometer correction assumes a linear decrease in the torque with respect to input power, from the 25% load point to the minimum load point with a coupled but unloaded dynamometer. This line can be extrapolated to the no-load power point where the torque is expected to be zero. The difference can be considered as the error to be corrected with a dynamometer correction factor. The slope of the line is calculated from Equation (4):

$$slope = \frac{T_{LLP} - T_{NLC}}{P_{LLP} - P_{NLC}} \tag{4}$$

where

T_{LLP} = measured motor torque at 25% load test point, N · m (see 8.2.1)
T_{NLC} = measured no-load motor torque with dynamometer coupled, N · m (see 8.2.1)
P_{NLC} = measured no-load input power with dynamometer coupled, kW (see 8.2.1)
P_{LLP} = measured motor input power at 25% load test point, kW (see 8.2.1)
P_{NLU} = measured no-load input power with dynamometer un-coupled, kW (see 8.2.1)

The dynamometer correction factor, in N · m, is given by:

$$T_W = slope \times \left(P_{NLC} - P_{NLU}\right) - T_{NLC} \tag{5}$$

The test is invalid if the dynamometer correction factor is greater than 5% of the full-load torque of the motor under test. The above method is also applicable for the torque measured in other units.

5.2.1.2 Rotating-shaft torque sensor

In this method, a loading device is coupled to the motor shaft through an in-line, rotating-shaft torque sensor.

5.2.1.3 Stator reaction

In this method, the motor is mounted to a torque table and the reaction torque produced by the motor is measured.

5.2.1.4 Inertia load

In this method, the motor torque is measured by measuring the acceleration of the motor with a known inertia. Care must be taken to include the rotor, shaft and coupling inertias in the calculation. Torque is calculated as shown in Equation (6):

$$T = I_T \alpha \tag{6}$$

where

I_T is the total inertia of the system, including the rotor, shaft, couplings and any load inertia

α is the acceleration due to the torque

5.2.2 Rotational speed

The instrumentation used to measure rotational speed shall not have an error greater than ± 1.0 r/min.

5.2.2.1 Stroboscopic methods

When measuring rotational speed using a stroboscope, the stroboscope should first be set at the synchronous speed of the motor under test and then reduced until the first sharp image is achieved. When the flash rate is set to zero and then increased, sharp images may be seen at sub-harmonics of the rotational speed.

5.2.3 Slip speed and slip

Slip speed is the difference between synchronous speed and measured rotational speed in r/min. Slip is usually expressed as the ratio of slip speed to synchronous speed [see Equation (7)].

$$s = \frac{slip\ speed}{synchronous\ speed} \tag{7}$$

where both slip speed and synchronous speed are in r/min.

Slip speed may be determined very accurately by using an electronic stroboscope. The slip speed is determined by subtracting the measured rotational speed in r/min from the synchronous speed for that motor construction and line frequency of the motor being measured.

Analog tachometers or speed counters are not sufficiently accurate for a measurement of slip. Stroboscopic or digital tachometer methods are recommended.

5.2.3.1 Slip correction for temperature

Slip measurements should be corrected to the specified stator temperature as shown in Equation (8):

$$s_s = \frac{s_t(t_s + k)}{(t_t + k)} \tag{8}$$

where

s_s is the corrected slip;
s_t is the measured slip at temperature t_t;
t_s is the specified temperature for slip correction (°C) (see 7.2.1);
t_t is the measured temperature of the winding (°C);
k is constant selected according to the stator wire type, for example,
k is 234.5 for 100% International Annealed Copper Standard (IACS) conductivity copper, and
k is 224.8 for aluminum, based on a volume conductivity of 62%.

5.2.4 Output power

The mechanical output power, P, is the product of torque, T, and angular velocity, ω, as shown in Equation (9).

$$P = T\omega \tag{9}$$

If SI units are used, torque is measured in N · m, angular velocity is measured in rad/seconds, and power is measured in W.

The rotational speed, n, is conventionally expressed in r/min, so that

$$n = \frac{60\omega}{2\pi} = 9.549\omega \tag{10}$$

$$P = \frac{Tn}{k} = \frac{Tn}{9.549} \tag{11}$$

For torque measured in other units, k must be adjusted appropriately as follows:

k is 7.043 for T (lbf·ft);
k is 84.52 for T (lbf · in);
k is 112.7 for T (ozf ·ft);
k is 1352 for T (ozf · in).

Mechanical output power may be determined by use of a brake or dynamometer.

5.2.5 Bearing loss stabilization

The friction loss in some motors may change until the bearings reach stabilized operating condition. Stabilization can be considered to have occurred whenever the input power at no-load, or coupled to a de-energized dynamometer, does not vary by more than 3% between successive readings obtained at half-hour intervals.

Stabilization may require a number of hours of running. All measurements to determine stabilization shall be obtained at the same voltage and frequency. Stabilization is only required for loss segregation of the no-load losses.

5.3 Temperature measurements

Temperature measurements are made to determine the ambient temperature and the temperature of certain parts of the motor when the motor is running at specified loads. The temperature rise of the windings over the ambient temperature may also be determined.

Commonly used methods of temperature determination are defined in IEEE Std 1-2000, Table 2, and as follows:

a) Applied thermocouple
b) Resistance
c) Embedded detector

Methods of measuring motor-winding temperature are described in IEEE Std 1-2000, IEEE Std 118-1978, and IEEE Std 119-1974.

5.3.1 Applied thermocouple method

The applied thermocouple method is defined in IEEE Std 1-2000, Table 2, as, “thermocouples are applied directly to the conductors or separated from the metallic circuit only by the integrally applied insulation of the conductor itself.” Integrally applied insulation for purposes of this standard is interpreted to include the varnish impregnation normally applied to motor windings.

Because the temperature reading of the thermocouple lags the winding temperature when it is changing, the thermocouple temperature may continue to increase after the winding has been de-energized. Therefore the winding temperature reported, which should be the highest recorded value, may be reached after the winding has been de-energized.

5.3.1.1 Selection of thermocouples

Thermocouple wire used should be of known calibration and should be accurate to within 2 ºF (1.1 ºC).

Iron-constantan thermocouples of 0.25 mm diameter (30 AWG) wire are recommended because of the relatively low heat flow from the junction out through the thermocouple wires. Because of this heat flow effect, copper-constantan thermocouples and thermocouples made of wire greater than 0.25 mm in diameter are not recommended. Thermocouples made of wire smaller than 0.25 mm in diameter are, in general, fragile and difficult to apply; they also may offer problems of accuracy of the thermoelectric potential generated at the junction unless calibrated before being used.

Thermocouple junctions may be formed by welding or soldering. The twisting of the wire at the junction should be kept to a minimum by removing any excess after forming so that the junction mass is as small as possible.

5.3.1.2 Method of application

The thermocouple junction should be held against the integrally applied insulation by cement. The cement used should not have a deleterious effect on the insulation. Commonly used cement is a mixture of fuller's earth and water glass (sodium silicate).

- A number of thermocouples should be applied to each energized motor winding under test on both ends of the motor with the objective of finding the hottest accessible area.
- The thermocouple junction must be in thermal contact with the integral insulation of the winding. The thermocouple junction must not be coated with any insulating material prior to attachment. There should be no cement between the thermocouple junction and the integrally applied insulation.
- A minimum amount of cement should be used to hold the thermocouple junction in position against the winding so that the mass surrounding the junction will be as small as possible.
- The thermocouple lead wire should be tied against the motor windings a sufficient distance (two to three inches) in order to minimize the transfer of heat from the junction out through the thermocouple leads and to provide strain relief.

5.3.1.3 Range of usage

Range of usage is determined by the type of thermocouple wire and cement used. The temperature range considered by this standard extends to 350 °C.

5.3.1.4 Instrumentation

It is recommended that solid-state thermocouple transducers with digital indication be used. The instrument used should have a speed of response consistent with the expected rate of change in temperature of the winding being measured.

5.3.2 Resistance method

Resistance method, as defined in IEEE Std 1-2000, Table 2, is the determination of the temperature by comparison of the resistance of a winding at the temperature to be determined with the resistance at a known temperature. The average temperature of the winding is obtained using this method.

Extreme care must be taken to secure accurate resistance measurements because a small error will cause a comparatively large error in the calculated temperature. Resistance measurements shall be made as outlined in IEEE Std 119-1974. IEEE Std 118-1978 (section 5.2) applies for temperature calculation. The average temperature of the winding may be calculated as shown in Equation (12):

$$t_h = \frac{R_h}{R_c}(k + t_c) - k \tag{12}$$

where

t_h is the average temperature of winding (°C);
R_h is the measured resistance, (Ω), at elevated temperature;
t_c is the ambient temperature (°C)
R_c is the measured resistance, (Ω), at ambient temperature;
k is a constant selected according to the wire type
k is 234.5 for 100% International Annealed Copper Standard (IACS) conductivity copper, and
k is 224.8 for aluminum, based on a volume conductivity of 62%.

5.3.2.1 Method of application

a) The cold resistance must be measured only after the motor has remained in a constant ambient temperature for a sufficient time for the winding to be at the ambient temperature.

b) For measurement after shutdown the initial hot resistance reading should be taken as quickly as possible after shutdown, before appreciable cooling of the winding has occurred. Linear regression may be used to more accurately determine the resistance at the time the power was disconnected. Using automatic instrumentation, the initial reading can be recorded within 30 s thereby eliminating the need for extrapolating values to zero time.

c) The same instrumentation should be used in taking the cold and hot measurements.

d) Any protective circuits in the motor should be bypassed to ensure the accuracy of resistance readings.

5.3.2.2 Range of usage

The constant *k* in Equation (12) provides results of the accuracy intended in this standard over a temperature range of 0 °C to 300 °C for commercial grades of copper and aluminum conductors.

5.3.2.3 Instrumentation

a) The use of digital instruments is recommended.
b) In the drop-of-potential method, a simplified approach is the use of a constant direct current power supply and a voltmeter to record the voltage drop across the winding. With the current adjustable and suitable zero suppression on the voltmeter, the output may be calibrated to read temperature directly.
c) A Kelvin double bridge should be used for resistances below 1.0 Ω.
d) The Wheatstone bridge method, using a three-lead bridge, may be used for windings with a cold resistance of approximately 1.0 Ω and above.
e) For windings with a cold resistance of 5 Ω or higher, any of the methods in 5.3.2.3 may be used.

5.3.3 Embedded-detector method

The embedded-detector method, as defined in IEEE Std 1-2000 “is based on the determination of the temperature by thermocouples or resistance temperature detectors, or other temperature measuring devices built into the equipment, either permanently or for testing, in specified locations.”

5.3.3.1 Usage

This method is useful to the design engineer during development of new motor designs to investigate hot spots and temperature gradients. In using this method, precautions should be taken similar to those for the applied-thermocouple method.

6. Tests

6.1 General

6.1.1 Circuit connections

The connections between the power source and the motor on test shall be as shown in Figure 2.

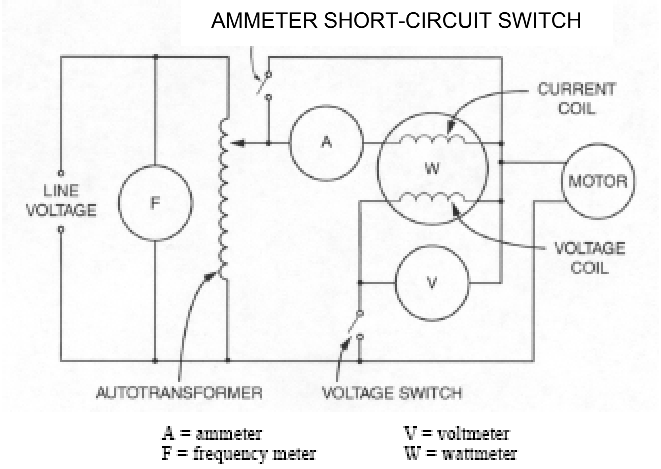

Figure 2—Variable voltage test connections

6.1.2 Ambient temperature

All performance determinations should be obtained with a reference ambient temperature of 25 °C. However, the ambient temperature under which the test is performed shall be not less than 10 °C, nor greater than 40 °C, unless otherwise agreed to by the purchaser and manufacturer.

The procedure and recommendations of IEEE Std 119-1974 shall be followed in measuring the ambient temperatures of electric motors.

6.2 Safety

Proper safety precautions shall be taken for all tests.

CAUTION

Dangerous currents, voltages and forces may be encountered during the test outlined in this standard. All test should be performed by knowledgeable and experienced personnel. This standard does not list or review the manifold safety precautions that are established throughout industry. Rather, only those special safety precautions applicable to the particular test are described.

7. Types of loss

7.1 General

The losses of an induction motor include:

- Stator I^2R loss
- Rotor I^2R loss
- Friction and Windage loss
- Core loss
- Stray loss
- Brush contact loss (for wound rotor induction motors)

The segregation of losses in single phase induction motors is generally more difficult than three phase induction motors due to the design of single phase machines and the availability of different types of single phase machines. A procedure is given in this chapter for the determination of the losses of the single phase machine with a single stator run winding.[7] The equivalent circuit is usually found useful in the calculation of losses and performance of the single phase machine. The equivalent circuit, based upon the revolving field theory, of the single phase machine with a single stator run winding is shown in Figure 3.

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[7] For motors with auxiliary windings such as permanent split capacitor motors and double capacitor motors the outlined procedures are not applicable. For a discussion of loss segration of such motors see Veinott, C. G., [B4], Theory and Design of Small Induction motors," McGraw Hill, 1959.

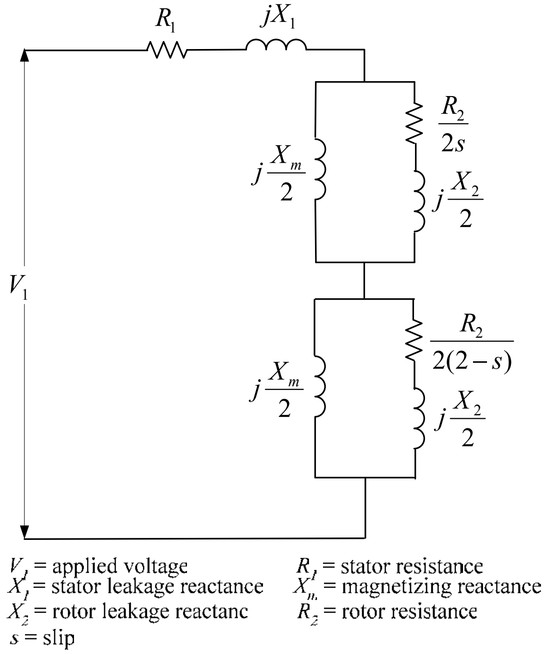

Figure 3—Equivalent circuit of a single-phase single run-winding induction motor

7.2 Stator resistive loss

The resistive loss of a stator winding, P_{sl}, is given by Equation (13).

$$P_{sl} = I^2 R \tag{13}$$

where

I is the measured stator winding current at a specified load (A);
R is the dc resistance between the line terminals, (Ω), corrected to the specified temperature (see 5.1.5.1).

7.2.1 Specified temperature

The *specified temperature* to be used when making resistance corrections shall be, in order of preference:

a) The temperature rise by resistance determined from a rated load temperature test (see Clause 10) plus 25 ºC standard ambient. Rated load is defined as the rated full load torque calculated , based on the rating identified on the nameplate at 1.0 service factor and full load speed, see 8.2.1.

b) Temperature rise determined by thermocouple or other temperature detectors plus 25 ºC standard ambient.

c) The temperature determined in a) for a motor of the same construction and electrical design.

d) A temperature taken from Table 2, according to the class of insulation.

This reference temperature should be used for determining resistive losses at all loads. If the rated temperature rise is specified as that of a lower class of insulation than that actually used in the construction of the motor, then the temperature for resistance correction should be that of the lower class of insulation.

Table 2—Specified temperature for resistance corrections

Class of insulation	Temperature (ºC)
A	75
B	95
F	115
H	130

7.3 Friction and windage loss

Friction and windage loss may be determined by the following methods.

To ensure that the correct value of friction and windage loss is obtained the motor shall be operated until the input power has stabilized (see 5.2.5).

7.3.1 Retardation method

For this method, the rotational moment of inertia of the rotating parts, *J*, must be known either by calculation or measurement. The motor is first run at no-load at rated voltage and frequency until the input power is stabilized. The motor is then disconnected from the line and allowed to decelerate. The rate of deceleration, *dn/dt*, is obtained by measurement of the time required for the speed to decrease by a fixed interval from no-load speed to rated motor speed, or by measurement of the change in speed for a fixed time interval within the same speed interval. The friction and windage loss, P_f, is calculated from the speed and the rate of deceleration by Equation (14):

$$P_f = knJ\left(\frac{dn}{dt}\right) \tag{14}$$

where

k is a constant selected according to the units of measure, k is 109.7×10^4 for J (kg .m^2);
n is the speed at which the rate-of-deceleration is measured (r/min);
J is the rotational moment of inertia of the rotor assembly (kg.m^2);
$\frac{dn}{dt}$ is the rate-of-deceleration (r/min)/s.

7.3.2 Dynamometer method

One method of determining the friction and windage loss is to measure the torque required to rotate a de-energized test motor at rated speed. The friction and windage loss, P_f, is then expressed in watts as shown in Equation (15).

$$P_f = \frac{T_f n}{k} \tag{15}$$

where

T_f is the net friction and windage torque (N · m);
n is the rotational speed (r/min);
k is a constant selected according to the units of measure (see 5.2.4).

7.3.3 No-load saturation method

The motor is run at no-load at rated frequency and voltage until the input power is stabilized. Readings are then taken of voltage, current, and input power at rated frequency for voltages ranging from 125% of rated voltage down to a point where further voltage reduction increases the current. The voltage adjustment can be accomplished by a variable-voltage transformer or other means. Immediately following this test and before the temperatures can change sensibly, a reading of input power and input current at approximately 50% of rated voltage should be taken with the rotor locked and with only the main or running winding excited. This test should be followed immediately by a measurement of the stator resistance.

If the input current at any voltage is I_s, the total resistive loss P_l in the motor at the same voltage is as shown in Equation (16).

$$P_l = \frac{I_S^2}{2}\left(R_t + \frac{P_L}{I_1^2}\right) \tag{16}$$

where

P_L is the input power with locked rotor at approximately 50% of rated voltage (W);
R_t is the measured stator resistance at the test temperature (Ω);
I_1 is the input current with locked rotor at approximately 50% of rated voltage (A).

The measured input power minus the resistive loss, P_l, is plotted as a function of voltage. When the curve so obtained is extended to zero voltage, the intercept with the zero voltage axis is the friction and windage loss. The intercept may be determined more accurately by plotting the input power minus resistive loss against the voltage squared for values in the lower voltage range.

For most practical purposes the friction and windage loss can be measured with sufficient accuracy by reading simply the minimum power input as the voltage is reduced and then subtracting the resistive loss as calculated by Equation (16).

7.3.3.1 No-load current

The current at no load is measured directly.

7.4 Core loss

When a motor is run at no-load, the measured input power is equal to the total loss, where the total loss at no-load is the sum of the stator resistive loss at the test temperature, rotor resistive loss at the test temperature, friction and windage loss (in the case of wound-rotor motors, the brush-friction loss is included in the friction and windage loss), and core loss.

At no-load when slip is negligibly small, the input power minus the stator resistive loss is equal to the sum of the friction and windage loss and the core loss. The core loss at no load is obtained by subtracting the value of friction and windage loss (obtained per 7.3) from the sum of friction and windage loss and core loss.

7.5 Rotor resistive loss

When slip can be accurately determined, the rotor resistive loss, *Prl*, should be determined from slip, *s* (see 5.2.3). In the case of wound-rotors, the rotor resistive loss includes the brush-contact loss (see 7.7). The rotor resistive loss is given by Equation (17):

$$P_{rl} = \left(P_0 - P_{sl} - P_{cl} - P_f\right)s \tag{17}$$

where

P_0 is the measured stator input power (W);
P_{sl} is the measured stator resistive loss (W);
P_{cl} is the core loss (W);
P_f is the friction and windage loss (W);
s is the slip.

It may be noted that under conditions of locked rotor P_f is zero and slip is unity. Equation (17) then reduces to the following as shown in Equation (18).

$$P_{rl} = \left(P_0 - P_{sl} - P_{cl}\right) \tag{18}$$

7.6 Stray-load loss

The stray-load loss is that portion of the total loss not accounted for by the sum of the friction and windage loss, stator resistive loss, rotor resistive loss, and core loss.

7.6.1 Indirect measurement

The stray-load loss is indirectly determined by measuring the total loss and subtracting the sum of the friction and windage loss, stator resistive loss, rotor resistive loss, and core loss.

7.6.2 Direct method for wound-rotor motors

In this method, the rotor is excited with direct current and the stator winding terminals are short-circuited with an ammeter included in the circuit. The rotor is driven by external means at synchronous speed; and 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 stray-load loss, P_{sll}, is then determined by using Equation (19).

$$P_{sll} = \left(P_r - P_f\right) - P_{sl} \tag{19}$$

where

P_r is the mechanical power required to drive the rotor with dc excitation (W);
P_f is the mechanical power required to drive the rotor without dc excitation (W);
P_{sl} is the stator resistive loss at test temperature (W).

7.6.2.1 Smoothing of test data

The accuracy of this method can be improved by plotting stray-load loss against stator current squared. The quantities P_{sll}, $(P_r - P_f)$, and P_{sl} are fit in the form of Equation (20).

$$P_i = A_i I^{N_i} \tag{20}$$

where

i is 1, 2, or 3;
P_i is $P_1 = P_{sll}$, $P_2 = (P_r - P_f)$, and $P_3 = P_{sl}$ (W);
A_i is the y intercept on a log-log plot;
N_i is the slope on a log-log plot;
I is the observed line current during the stray-load loss test.

7.6.3 Assumed stray-load loss

If stray-load loss is not measured, and it is acceptable by applicable standards or by contract specification,the value of stray-load loss at rated load may be assumed to be 1.8% of the rated output power.

For other than rated load, it shall be assumed that the stray-load loss, $\tilde{P}_{sll}$, is proportional to the ratio of measured torque to rated torque squared , as shown in Equation (21).

$$\tilde{P}_{sll} = P_{sll}\left(\frac{T}{T_0}\right)^2 \tag{21}$$

where

P_{sll} is the assumed value of stray-load loss at rated load (W);
T is the value of torque measured at the load point (Nm);
T_0 is the value of torque at rated load (Nm), calculated according to Equation (24).

7.7 Brush-contact loss

For wound-rotors, the brush-contact loss should be determined by the product of the calculated secondary current and a voltage drop. The voltage drop may be assumed to be 1.0 V for carbon and graphite brushes, and 0.3 V for metal-carbon brushes.

8. Efficiency and power factor

8.1 General

Motor efficiency, η, is the ratio of output power, P_{out}, to input power, P_{in} as illustrated in Equation (22).

$$\eta = \frac{P_{out}}{P_{in}} \tag{22}$$

Alternatively, since output power is equal to the input power minus the total loss, the efficiency may also be determined by Equation (23).

$$\eta = \frac{P_{in} - P_l}{P_{in}} \tag{23}$$

where

P_l is the total loss (see Clause 7).

8.2 Determination of efficiency

A determination of efficiency is based on measurements of input power and output power. Efficiency is calculated as the ratio of the measured output power to the corrected input power, where the measured input power is corrected for ambient temperature (see 8.2). A dynamometer correction is also made, if applicable (see 5.2.1.1.1).

8.2.1 Test procedure

The motor is loaded at rated full load by means of a dynamometer (see 5.2.4) until it is thermally stable. Rated load is defined as the rated full load torque calculated, based on the rating identified on the nameplate at 1.0 service factor and full load speed according to Equation (24). Thermal stability shall be defined as a condition by which the motor temperature does not change by more than 1 ºC over a 30 min period. For air-over motors adequate air shall be supplied to maintain a winding temperature in the range of 70 ºC –80 ºC.[8]

$$T = \frac{kP}{n} \tag{24}$$

where

T is the torque in N · m
n is motor nameplate speed (rpm)
P is motor nameplate power (W)
k is 9.549 for T in N · m
(for torque in other units, k is a constant selected according to the units of measure (see 5.2.4*).*

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[8] The temperature range was specified to enable relative comparability of efficiency number for these motors.

Following the thermal stability, the machine shall be subjected to loads at four load points of approximately 25%, 75%, 50%, and 100% load, and two additional load points above 100% load, but not to exceed 150% load. In loading the machine, start at the highest load point and move in descending order. The temperature of the stator winding during the loading shall be within 10 ºC of the hottest temperature reading recorded during the rated load temperature test.

The efficiency shall be determined for a minimum of six load points. Readings of electrical power, current, voltage, frequency, slip, torque, ambient temperature, and stator winding temperature or stator winding resistance should be obtained at each load point. The stator main winding resistance and ambient temperature shall be measured within 30 s following thermal stability in accordance to 10.3.1.4 and used for the purpose of resistance correction to a standard ambient, unless the ambient temperature is within 25 ºC ± 5 ºC.

8.2.2 Calculation form

Motor efficiency shall be determined as outlined in Form 3 (see A.3). The stator resistive loss and the slip speed are to be corrected for temperature as indicated in Form 3 unless the ambient temperature is within 25 ºC ± 5 ºC. Dynamometer correction should be made, if applicable (see 5.2.1.1.1). The dynamometer correction should be made with the same direction of rotation used during the load test.

8.3 Power factor

The power factor, *PF*, is the ratio of measured input power, P_{in}, to the product of voltage, V, and current, I, as illustrated in Equation (25).

$$PF = \frac{P_{in}}{VI} \tag{25}$$

All instruments should be read as simultaneously as practical.

9. Performance tests

The motor temperature at the start of every test shall be not less than 10 ºC nor greater than 40 ºC, unless otherwise agreed to by the purchaser and manufacturer.

9.1 Definitions

9.1.1 Speed-torque characteristic

The speed-torque characteristic is the relation between torque and speed, for speeds ranging from zero to synchronous speed. This relation, when expressed as a curve, will include breakdown torque, pull-up torque, and locked-rotor torque. In the case of synchronous motors, the speed-torque curve will also include the pull-in torque. Representative speed-torque curves are shown in Figure 4.

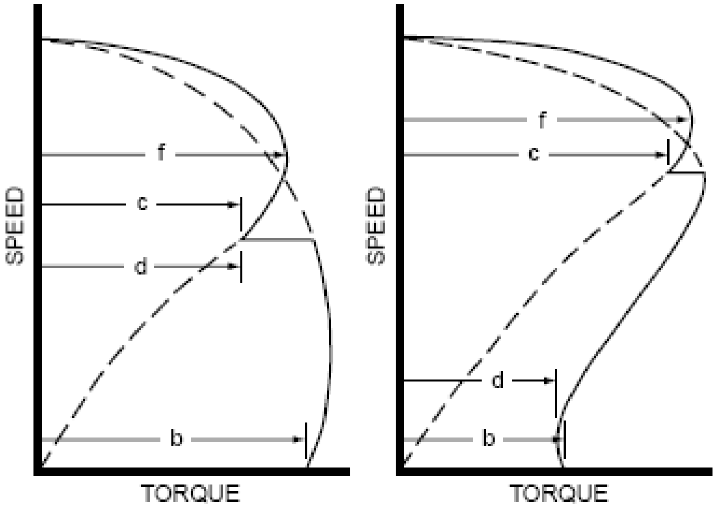
9.1.2 Speed-current characteristic

The speed-current characteristic is the relation between equipment current and speed, for speeds ranging from zero to synchronous speed. The speed-current characteristic is generally plotted together with the speed-torque characteristic, using a common speed scale for both curves.

9.2 Tests for speed-torque and speed-current characteristics

9.2.1 Procedure

The following methods may be used to determine the speed-torque and speed-current characteristics. Sufficient data should be recorded to ensure that reliable curves can be drawn in the regions of interest.



b = locked-rotor torque
c = switching torque
d = pull-up torque
f = breakdown torque

Figure 4—Representative speed-torque characteristic curves of a single-phase induction motor

The frequency of the power supply shall be maintained constant at the rated value for the motor throughout the test (see 4.2).

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

The motor winding temperature should be its normal operating temperature.

9.2.1.1 Method 1—measured output

The motor under test is coupled to a dynamometer or other suitable load such that the motor speed is controlled by varying the load. The friction and windage losses of the load must be previously determined.

The measured values of torque are to be corrected by adding to them a torque corresponding to the friction and windage loss associated with the load.

Data are obtained at speeds between approximately 1/3 synchronous speed and the maximum speed. The speed should be constant when data are recorded, so that acceleration and deceleration power does not affect the recorded values. Readings of voltage, current, and torque are obtained at each speed setting.

Care should be taken not to overheat the motor.

The total power output is the sum of the measured output power and the losses associated with the load.

Thus the torque, T, at each speed, n, is calculated using Equation (26), as follows:

$$T = \frac{k(P_0 + P_l)}{n} \tag{26}$$

where

T is the torque (N · m);
k is a constant selected according to the units of measure (see 5.2.4);
P_0 is the output power (W);
P_l is the friction and windage loss of the load (W);
n is the test speed (r/min).

9.2.1.1 Method 2—acceleration

For this method, the rotational moment of inertia of the rotating parts must be known either by calculation or by measurement. As the motor accelerates from rest to near synchronous speed, simultaneous readings of the current and speed are obtained at fixed time intervals. The torque, T, at each speed is calculated using Equation (27) as follows:

$$T = \left(\frac{J}{k}\right)\left(\frac{dn}{dt}\right) \tag{27}$$

where

T = the torque (N · m);
dn/dt = the acceleration (r/min · seconds);
J = the rotational moment of inertia (kg · m2)
k = 109.7 ·10–4 for these units of measure.

When this method is applied to motors of approximately 40 W or less, it is recommended that the speed be measured by stroboscopic methods (see 5.2.1.1).

9.2.1.2 Method 3—input

In this method, the torque is determined by subtracting the losses from the input power.

The input readings called for in 9.2.1.2 are plotted against the speed. The line voltage, power, and speed should be plotted as a function of time. Average values of the zero speed readings from the locked test should be included.

The torque, T, at each speed is determined from the input power using Equation (28):

$$T = \frac{k}{n}(P_i - P_l) - T_{fw} \tag{28}$$

where

T is the torque (N · m);
K is a constant selected according to the units of measure (see 5.2.4);
P_l is the stator resistive loss (W);
P_i is the input power (W);
n is the test speed (r/min);
T_{fw} is the motor friction and windage torque at speed n (N · m).

9.2.1.3 Method 4—direct measurement

The speed-torque and speed-current tests should be made by a continuous data acquisition method. When equipment for continuous data acquisition is not available, these tests may be made with a dynamometer method. Tests shall be made at rated voltage using a regulated power supply. When the dynamometer method is used, the speeds at which torque is determined shall be chosen at such intervals as to permit plotting the maximum torques of the fundamental characteristics; and also to permit the plotting of the maxima and minima of synchronous or asynchronous irregularities caused by higher order harmonics when they are present in an appreciable degree.

9.3 Locked-rotor current

The locked-rotor current shall be obtained at the rated frequency, and the measured voltage shall be within 5% of the rated voltage. The measured locked-rotor current shall be corrected for any departure from the rated voltage by multiplying the measured current by the rated voltage and dividing the product by the measured voltage.

All readings shall be taken as quickly as possible after voltage is applied. The period of time between the application of voltage and measurement shall not exceed 5 s.

9.4 Locked-rotor torque

Motor torque depends on the angular position of the rotor with respect to the stator. The locked-rotor torque is defined as the minimum torque developed at rest in any angular position of the rotor. The locked-rotor torque is best determined by plotting torque versus the angular position of the rotor. Such a plot may be obtained by direct measurement tests at several angular positions of the rotor or by methods of continuous data acquisition.

9.5 Pull-up torque

The pull-up torque of an alternating-current motor is the minimum external torque developed by the motor during the period of acceleration from rest to the speed at which breakdown torque occurs. For motors that do not have a definite breakdown torque, the pull-up torque is the minimum torque developed up to rated speed.

The pull-up torque may best be determined by continuous data acquisition method, but may also be determined by brake or dynamometer.

9.6 Switching torque

Switching torque applies to motors that have an automatic connection change in the starting interval. The switching torque of a motor is the minimum external torque developed by the motor as it accelerates through switch-operating speed. It should be noted that if the torque on the starting connection is never less than the switching torque, the pull-up torque is identical to the switching torque. However, if the torque on the starting connection falls below the switching torque at some speed below switch-operating speed, the pull-up and switching torques are not identical. The difference between pull-up and switching torque is illustrated in Figure 4.

The switching torque may be determined by the following procedure. The motor is allowed to run at no-load and the torque load is gradually increased until the speed falls off abruptly and the starting switch recloses. With this torque setting the motor may either fall off in speed or hunt, that is, the speed may cycle between the upper and lower speeds. In either case the torque load should be reduced until the motor transfers and remains on the running connection.

An alternative method is to start the motor from rest with a high torque load and then gradually decrease the load until the motor transfers and remains on the running connection.

9.7 Breakdown torque

This test is best performed by the continuous data acquisition method. Direct measurement methods are also adequate but are more dependent on operator skill. When a direct measurement method is used, this test may be made by allowing the motor to run light and then increasing the torque until the speed of the motor falls off abruptly. This test should be made as rapidly as possible, consistent with accuracy, but not so rapidly as to introduce inertia errors into the readings.

10. Temperature tests

10.1 Purpose and scope

Temperature tests are made to determine the temperature rise of certain parts of the motor above the ambient temperature when running under a specified load. Subclause 10.2 to 10.4 describes test procedures and the treatment of data.

10.2 General instructions

During a measurement to determine temperature rise, the motor shall be shielded from air currents coming from pulleys, belts, and other outside sources. A very slight current of air can cause large discrepancies in temperature rise results. Conditions that produce rapid change in ambient air temperature shall not be considered satisfactory for temperature rise tests. Sufficient floor space should be provided between motors to allow free circulation of air.

10.2.1 Measuring devices

Temperature measuring devices shall be in accordance with IEEE Std. 119-1974.

At the start of temperature tests all instruments shall be checked to ensure that there are no appreciable instrument errors due to stray field effects.

10.2.2 Methods of measuring temperatures

A discussion of suitable methods for temperature measurements is provided in 5.3.

10.2.3 Measurement of ambient temperature

The ambient temperature shall be measured in accordance with the procedures provided in IEEE Std 119-1974.

10.3 Measurement of temperature rise

When the motor is ventilated by the immediately surrounding air, the temperature rise is the observed motor temperature less the ambient temperature. When the motor is ventilated by air obtained from a remote source or a heat exchanger, the temperature rise is the observed motor temperature less the temperature of the ingoing air. The observed motor temperature shall be considered to be the maximum temperature reading obtained prior to or after shutdown.

In general, the temperature rise increases with altitude. Motors may be tested at any altitude not exceeding 1000 m and with cooling air temperatures between 10 ºC and 40 ºC without correction of temperature rise. While an exact correction 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 expected temperature rise at sea level.

10.3.1 Procedure

The motor shall be loaded by means whereby the load may be adjusted and held constant. The test shall be made at rated voltage and frequency. The loading may be determined by direct measurement of input or output power. A motor having more than one rating shall be tested at the rating that produces the greatest temperature rise. If it is not known which loading will produce the greatest temperature rise, the motor shall be separately tested at each rating.

10.3.1.1 Initial conditions

When testing motors not rated for continuous operation, a short-time test shall commence only when the motor parts are within 5 ºC of the ambient temperature, unless otherwise specified.

10.3.1.2 Permissible overloading

When testing motors rated for continuous operation, reasonable overloads up to 150% of rated load are permissible during the preliminary heating period in order to shorten the time of test. Any overload should be removed before the temperature goes above the final expected temperature.

10.3.1.3 Termination of test

When testing motors rated for continuous operation, temperature readings shall be taken at intervals not less than 30 minutes for medium motors and not less than 15 minutes for small motors.[9] The temperature test shall continue until the change in temperature between two successive readings is 1 ºC or less.

When testing motors not rated for continuous operation, the test shall be continued for the specified time or until constant temperatures have been reached.

10.3.1.4 Resistance at shutdown

Measurement of temperatures after shutdown requires rapid deceleration and stopping of the motor.

Temperatures should be taken of the hottest parts that can be made quickly accessible by the removal of covers or small parts. Temperatures after shutdown shall be measured as frequently as possible until the temperature readings have begun a decided decline from their maximum values.

If the initial resistance reading at shutdown is obtained within 30 s after power is switched off, this reading is accepted as the resistance reading for temperature measurement.

If the initial resistance reading at shutdown cannot be made within 30 s after power is switched off, it shall be made as soon as possible, and subsequent resistance readings shall be taken at intervals of 30 s to 60 s for a minimum of ten readings.

A curve of these readings shall be plotted as a function of time, and shall be extrapolated to a time delay of 30 s. A semi-logarithmic plot is recommended, in which resistance is plotted on the logarithmic scale. The value of resistance thus obtained, through the extrapolation, shall be considered as the resistance reading for temperature measurement.

10.3.1.5 Care in measurement

Extreme care shall be taken to secure accurate resistance measurements, since a small error in measuring resistance will cause a comparatively large error in determining the temperature. Resistance measurements shall be made as outlined in IEEE Std 118-1978.

10.3.2 Core

Core temperature readings should be taken in at least two peripherally spaced locations on the external surface of the core near the vertical centerline. Alternate locations on the outside of the frame near the vertical centerline may be used.

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[9] The terms *small motor* and *medium motor* are defined in ANSI/NEMI MG1-2006 (Rev 1-2007) Section 1.

10.3.3 Bearings

a) *Liquid film type (sleeve or thrust).* The temperature readings should be those taken at a point as near the bearing surface as possible.
b) *Ball or roller type.* The temperature readings should be those taken at a point on the stationary race.

10.4 Measurement of rapidly changing temperature on windings

This subclause is provided to describe the methods used for the measurement of rapidly changing temperatures of small induction motor windings and to give information regarding the characteristics and limitations of these methods and of the instruments used.

10.4.1 Temperature sensing elements

The value measured with temperature-sensing elements applied to motor windings depends upon the flow of heat from the winding conductor material to the element. Because of the thermal gradient resulting from this heat flow, sensing elements cannot measure the true conductor temperature without error if the conductor temperature is changing. The magnitude of this error arising from heat flow or thermal lag is dependent upon the following:

a) Rate of change of the winding conductor temperature,
b) Thermal resistance between the winding conductor and the sensing element,
c) Thermal capacity of the sensing element,
d) Thermal conductance between the element and the ambient.

11. Miscellaneous tests

11.1 Insulation resistance

Insulation resistance tests are not usually made on new motors unless they are specifically requested. For maintenance purposes, insulation tests are of value. All accessories, such as surge capacitors, surge arrestors, current transformers, etc, that have leads connected to the motor terminals shall be disconnected during test.

The leads shall be connected together and connected to the frame or core during test. For test methods, IEEE Std 43-2000 should be followed.

11.2 High-potential test

Refer to ANSI/NEMA MG 1-2006 (Rev 1 – 2007), Part 12.

11.3 Noise

Refer to ANSI/NEMA MG 1-2006 (Rev 1 – 2007), Part 9.

11.4 Vibration

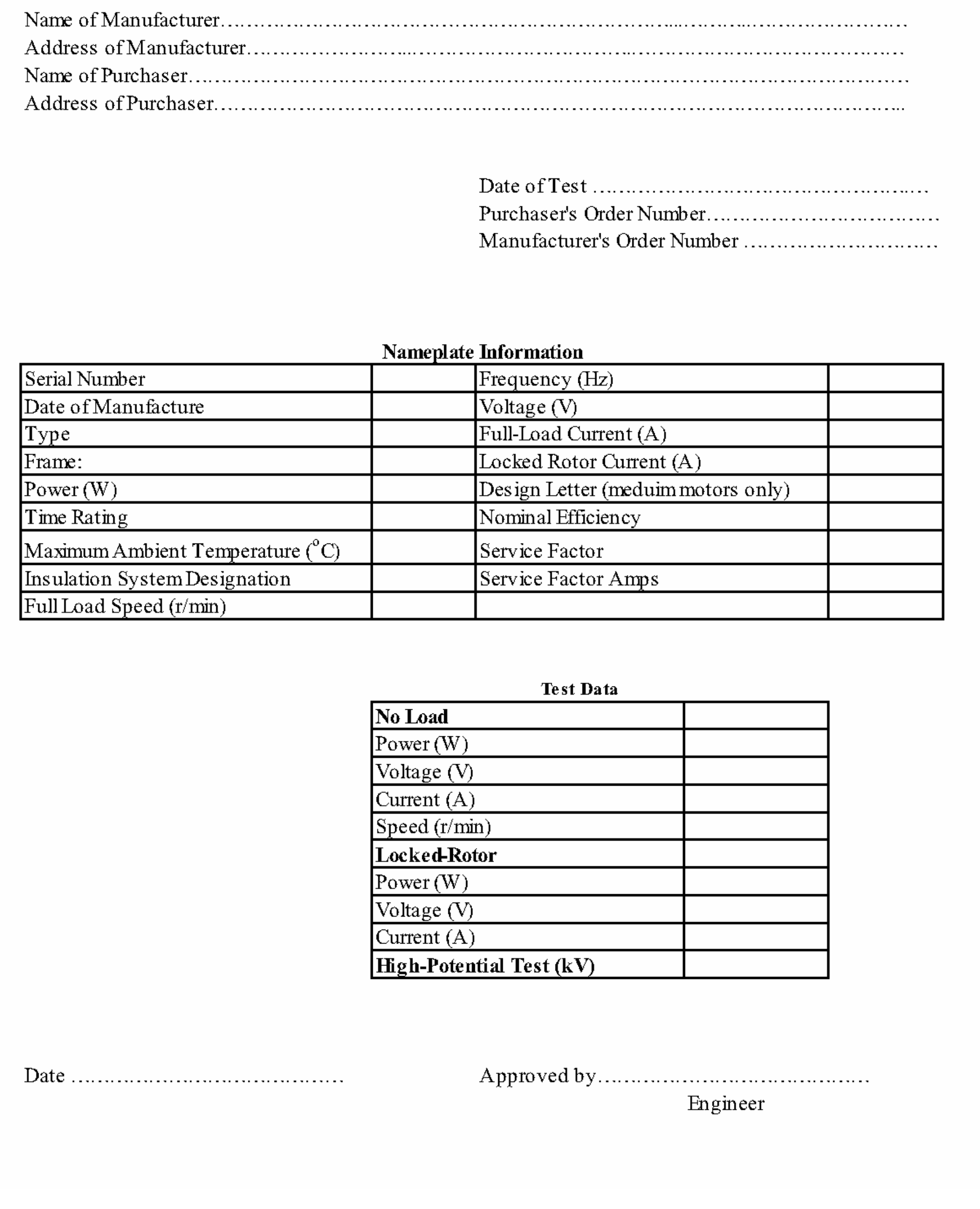
Refer to ANSI/NEMA MG 1-2006 (Rev 1 – 2007), Part 7.

Annex A

(informative)

Forms[10]

A.1 Form 1: Report of routine test of a single-phase motor



Name of Manufacturer……………………………………………………………………………………………
Address of Manufacturer…………………………………………………………………………………………
Name of Purchaser…………………………………………………………………………………………………
Address of Purchaser……………………………………………………………………………………………

Date of Test ………………………………………………
Purchaser's Order Number…………………………………
Manufacturer's Order Number …………………………

Nameplate Information

Serial Number		Frequency (Hz)	
Date of Manufacture		Voltage (V)	
Type		Full-Load Current (A)	
Frame:		Locked Rotor Current (A)	
Power (W)		Design Letter (meduim motors only)	
Time Rating		Nominal Efficiency	
Maximum Ambient Temperature (^{o}C)		Service Factor	
Insulation System Designation		Service Factor Amps	
Full Load Speed (r/min)			

Test Data

No Load	
Power (W)	
Voltage (V)	
Current (A)	
Speed (r/min)	
Locked-Rotor	
Power (W)	
Voltage (V)	
Current (A)	
High-Potential Test (kV)	

Date ……………………………………… Approved by……………………………………
Engineer

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[10] Copyright release for forms: Users of this standard may freely reproduce the forms in this Annex so that it can be used for its intended purpose and may further publish the completed forms.

A.2 Form 2: Report of complete test of a single-phase motor

Name of Manufacturer…………………………………………………………………..………..………………….
Address of Manufacturer…………………..……………………………….………………………………….
Name of Purchaser……………………………………………………………………………………………….
Address of Purchaser……………………………………………………………………………………...

Date of Test ………………………………………….….
Purchaser's Order Number…………………………….….
Manufacturer's Order Number ………………………..….

Nameplate Information

Serial Number		Frequency (Hz)	
Date of Man		Voltage (V)	
Type		Full-Load Current (A)	
Frame:		Locked Rotor Current (A)	
Power (W)		Design Letter (meduim motors only)	
Time Rating		Nominal Efficiency	
Maximum Ambient Temperature (°C)		Service Factor	
Insulation System Designation		Service Factor Amps	
Full Load Speed (r/min)			

Test Data

	Conditions of Test			Temperature Rise (°C)	
				Stator Windings	Rotor Windings
				(Cross out two) by Resistance Thermometer Thermocouple	(Cross out two) by Resistance Thermometer Thermocouple
Hours Run	Voltage (V)	Current (A)	Cooling Air(°C)		

Performance Characteristics

Full-Load Slip	No-load Current	Resistance at 25oC (Ω)	**Breakdown Torque (Cross-out three)**	Locked Rotor Torque (Cross-out three)	Locked Rotor Current (A)	High-Potential Test Voltage
		Start Wdgs Run Wgds	Nm ozf.in ozf.ft lbf.ft _____%V	Nm ozf.in ozf.ft lbf.ft _____%V	____%V	Start Windings Run Windings

Efficiencies and Power Factors

Efficiency (%)			Power Factor (%)		
Rated Load	**75% Load**	**50% Load**	Rated Load	**75% Load**	**50% Load**

Date ……………………………………   Approved by……………………………………
Engineer

A.3 Determination of motor efficiency

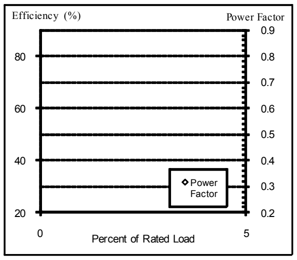
A.3 Form 3: Determination of Induction motor efficiency

Single Phase Induction Motor Efficiency Test Report

Test Date:
Report Date: 11-Mar-10

Test Laboratory's Motor ID #:

Motor Nameplate Information			
Serial Number		Frequency	
Manufacturer		Voltage	
Type		Full-Load Current	
Frame:		Locked Rotor Current	
Output Power (W)		Design Letter	
Time Rating		Nominal Efficiency	
Maximum Ambient Temperature (ºC)		Service Factor	
Insulation System Designation		Service Factor Current	
Full Load Speed (r/min)			



Test Data

Resistance & Temperature Measurements of Stator Main Winding

	Temperature	**Resistance (ohm)**	**Ambient**	**Temperature Rise**	
Initial	(A1)	(A3)	(A5)	Measured (°C)	(A7)
Full Load Heat Run	(A2)	(A4)	(A6)	By Res. (°C)	(A8)
Specified Temperature, t_S (°C)	(A9)				

Item	**Nominal (targeted) % Load**	**25**	**50**	**75**	**100**	**115**	**125**
	Test Point #	**1**	**2**	**3**	**4**	**5**	**6**
1	Ambient Temperature (°C)						
2	Stator Main Winding Temp t_t (°C)						
3	Frequency (Hz)						
4	Slip speed (r/min)						
5	Corrected Slip Speed (r/min)						
6	Speed (r/min)						
7	Torque (Nm)						
8	Dynamometer Correction						
9	Corrected Torque						
10	Output Power (W)						
11	Voltage (V)						
12	Current (A)						
13	Input Power (W)						
14	Stator resistive loss at t_t (W)						
15	Stator resistive loss at t_S (W)						
16	Input Power Correction (W)						
17	Corrected Input Power (W)						
18	Power Factor (%)						
19	Efficiency (%)						

Summary of Test Characteristics

20	Measured Load (% of rated Torque)						
21	Power Factor (%)						
22	Efficiency (%)						
23	Speed (rev/min)						
24	Line Current (A)						

A.4 Explanatory notes for form 3, test data

Item	Description/Calculation
1	Ambient temperature is determined in accordance with 6.1.2.
2	The stator winding temperature during test, t_t, is determined from stator resistance measurement or other temperature measurement, see Clause 10.
3	Frequency, see 4.2.
4	Slip speed, see 5.2.3.
5	Corrected slip speed, see 5.2.3.1 and 8.2.2.
6	Speed (corrected speed) is equal to [(synchronous rpm) – (Item 5)], see 5.2.2 and 5.2.3.1.
7	Measured torque, see 5.1.1.
8	Dynamometer correction, see 5.2.1.1.1.
9	The corrected torque is equal to [(Item 7) + (Item 8)].
10	Output power is equal to [(Item 6) × (Item 9)] / 9.549, see 5.2.4.
11	Voltage, see 5.1.2.
12	Stator current, see 5.1.3.
13	Input power, see 5.1.4.
14	The stator resistive loss at t_t, (see 7.2)
15	The stator resistive loss at the specified temperature for resistance correction, t_s, see 7.2.1.
16	The correction to input power is equal to [(Item 15) – (Item 14)].
17	The corrected input power is equal to [(Item 13) + (Item 16)].
18	Power factor is equal to [100 × (Item 13)] / [(Item 11) × (Item 12)], see 8.3.
19	Efficiency is equal to [100 × (Item 10) / (Item 17)], see 8.1.
20	The Measured torque (%) is equal to[(Item 7) / [rated torque calculated in Equation (24))]
21	Item 18
22	Item 19
23	Item 6
24	Item 12
A1	Measured cold motor winding temperature, see 5.2.3 (*used in Equation (12) as* t_c)[11]
A2	Measured hot motor winding temperature after heat run, see 5.3
A3	Measured cold motor winding resistance prior to heat run, see 5.3.2 (*used in Equation (12) as* R_c)
A4	Measured hot motor winding resistance at conclusion of heat run, see 5.3.2 (*used in Equation (12) as* R_h)
A5	Measured initial ambient temperature prior to heat run, see 5.3.2 [11]
A6	Measured ambient temperature at conclusion of heat run, see 8.2.1
A7	Equals to [(Item A2) – (Item A6)]
A8	Equals to [temperature calculated by *Equation (12)* minus A6]
A9	Specified temperature for resistance correction, t_s, see 7.2.1. Item A9 equals (A8+25 ºC)

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[11] The initial ambient temperature (A5) and cold motor winding temperature (A1) should be equal for a motor that is in steady state ambient conditions.

Annex B

(informative)

Bibliography

[B1] IEEE Std 4-1995, IEEE Standard Techniques for High-Voltage Testing.

[B2] IEEE Std 4a-2001, Amendment to IEEE Standard Techniques for High-Voltage Testing.

[B3] IEEE 100, *The Authoritative Dictionary of IEEE Standards Terms*, Seventh Edition.

[B4] Veinott, C. G., "Theory and Design of Small Induction Motors," McGraw-Hill, 1959.