**IEEE Std 114™-2001**
(Revision of IEEE Std 114-1982)

IEEE Standards

# 114™

# IEEE Standard Test Procedure for Single-Phase Induction Motors

**Industry Applications Society**

Sponsored by the
Electric Machines Committee

IEEE

Published by
The Institute of Electrical and Electronics Engineers, Inc.
3 Park Avenue, New York, NY 10016-5997, USA

24 May 2002

Print: SH94969
PDF: SS94969

*Recognized as an*
American National Standard (ANSI)

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**Industry Applications Society**

Approved 2 May 2002
**American National Standards Institute**

Approved 6 December 2001
**IEEE-SA Standards Board**

**Abstract:** Instructions are given for conducting and reporting the more generally applicable and acceptable tests to determine the performance characteristics of single phase induction motors. Electrical measurements, performance testing, temperature tests, and miscellaneous tests are covered.

**Keywords:** electric motor, induction, single phase, test

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The Institute of Electrical and Electronics Engineers, Inc.
3 Park Avenue, New York, NY 10016-5997, USA

Published 24 May 2002. Printed in the United States of America.

*Print:* ISBN 0-7381-3080-X SH94969
*PDF:* ISBN 0-7381-3081-8 SS94969

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# Introduction

(This introduction is not part of IEEE Std 114-2001, 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 who use electric motors and purchase electric motors from manufacturers.
- Individuals or organizations who acquire electric motors for resale to other individuals or organizations.
- Individuals or organizations who 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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# Contents

# IEEE Standard Test Procedure for Single-Phase Induction Motors

## 1. Overview

This standard test procedure is divided into 13 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, including non-excited synchronous 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 test procedure is meant to provide tests for use in evaluating the performance of single-phase induction motors.

## 2. References

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 If the following standards are superseded by an approved revision, the revision shall apply.

IEEE Std 1™-1986 (Reaff 1992), IEEE Standard General Principles for Temperature Limits in the Rating of Electric Equipment and for the Evaluation of Electrical Insulation.[1], [2]

IEEE Std 4™-1995, IEEE Standard Techniques for High-Voltage Testing.

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

IEEE Std 85™-1973 (Reaff 1986), IEEE Test Procedure for Airborne Sound Measurements on Rotating Electric Machinery.[3]

IEEE Std 118™-1978 (Reaff 1992), 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.[4]

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

ANSI/NEMA MG 1-1998 (Revision 1, 2000), Motors and Generators.[5]

## 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 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 a 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 *The Authoritative Dictionary of IEEE Standards Terms*, Seventh Edition :[6]

a) Locked-rotor current
b) Locked-rotor torque
c) Pull-up torque

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[2] IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA (http://standards.ieee.org/).

[3] IEEE Std 85-1973 has been withdrawn; however, copies can be obtained from Global Engineering, 15 Inverness Way East, Englewood, CO 80112-5704, USA, tel. (303) 792-2181 (http://global.ihs.com/).

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

[5] ANSI publications are available from the Sales Department, American National Standards Institute, 25 West 43rd Street, 4th Floor, New York, NY 10036, USA (http://www.ansi.org/).

[6] The numbers in brackets correspond to those of the bibliography in Annex B.

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—Tests applicable to single-phase motors**

| | **Test types** | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | **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 |
| **Shaded-pole** | 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 |
| **Reluctance (synchronous)** | X | X | X | | X | X | X | X | X | X | X |
| **Universal**[a] | X | X | | | | | | X | X | X | X |

[a] The tests listed apply to operation on alternating current only.

## 3.2 Tests with load

Tests with load are made for the purpose of determining efficiency, power factor, speed, and temperature rise. Some of the miscellaneous tests outlined in Clause 11 are also made with load. For all tests with load, the motor shall be properly aligned and securely fastened. For readings to be used in performance determinations, the motor temperature rise shall be between 50% and 100% of rated temperature rise. 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 seconds. 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 the 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 nonelectronic analog instruments, are

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

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

The indicating instrument shall bear record of calibration, within 12 months of the test, indicating limits of the error no greater than ±0.5% of full scale for general testing and no greater than ±0.2% for a determination of efficiency. 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 (nonelectronic) 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

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 nonelectronic 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.[7]

### 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 0.5%.

## 4.2 Power supply

The power supply voltage shall closely approach a sinusoidal waveform. The voltage waveform deviation factor, as defined in IEEE 100™ , 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.

# 5. Measurements

## 5.1 Electrical measurements

### 5.1.1 RMS quantities

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

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[7] For information on references, see Clause 2.

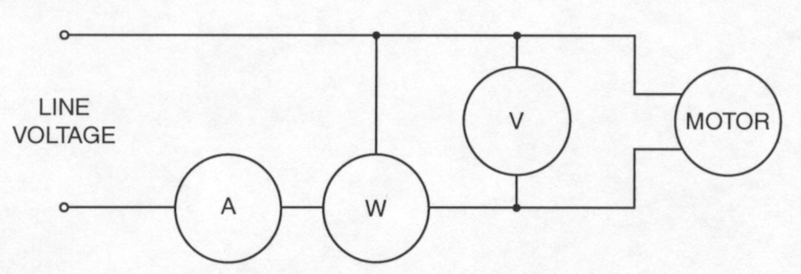
### 5.1.2 Voltage

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 auto-transformer, by an induction regulator, or by a controlled motor-generator set.

### 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.



A = ammeter W = wattmeter
V = voltmeter

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);
$P_W$ 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 $I_A \geq 7E/R_M$ holds.

### 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. Where a properly selected power transducer is used, the transducer loss shall be 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 performance determinations should be corrected to an 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 follows:

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

where

$R_s$ is the corrected winding resistance (Ω);
$R_t$ is the measured winding resistance, (Ω), at temperature $t_t$;
$t_s$ 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 225 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 brake or beam, with a rotating-shaft torque sensor, or by stator reaction.

### 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

Stroboscopic methods are recommended when a motor of approximately 40 W or less is tested, due to the load added by the tachometer. Either an electronic or a mechanical stroboscope is satisfactory.

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 rational intervals 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

$$s = \frac{\text{slip speed}}{\text{synchronous speed}} \tag{4}$$

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. When a stroboscope is used, the power supply for the stroboscope should have the same frequency as the motor power supply.

#### 5.2.3.1 Slip correction for temperature

Slip measurements should be corrected to the specified stator temperature as follows:

$$S_s = \frac{S_t(t_s + k)}{(t_t + k)} \tag{5}$$

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);
$t_t$ is the measured temperature of the winding (°C);
$k$ is a 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 225 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,

$$P = T\omega \tag{6}$$

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

$$n = \frac{60\omega}{2\pi} = 9.549\omega \tag{7}$$

$$P = \frac{Tn}{k} = \frac{Tn}{9.549} \tag{8}$$

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.

#### 5.2.4.1 Brake

In this method a brake is mounted on the motor shaft and is so arranged that a scale will read the retarding force offered by the brake. The torque is computed from the product of the scale reading and the length of the brake arm. Care shall be exercised in the construction and use of the brake. The tare, if present, shall be determined and compensated for.

#### 5.2.4.2 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 that 15% of the rated output of the motor. The dynamometer should be sensitive to a change in torque of 0.25% of the rated torque.

##### 5.2.4.2.1 Dynamometer correction

The dynamometer correction is a correction to the measured torque. The correction is based on measurements of the input power with the motor running alone and with the motor coupled to the dynamometer. Both measurements of input power are obtained with the motor running at the same speed.

Measured values of torque are corrected by adding a torque corresponding to the friction and windage loss associated with the dynamometer. The allowance for this loss is made by adding a torque

$$T_w = \frac{k(P_a - P_b)}{n} \tag{9}$$

where

$P_a$ is the input power to the motor driving the dynamometer (W);
$P_b$ is the input power to the motor running alone (W);
$n$ is the rotational speed (r/min);
$k$ is a constant selected as in 5.2.4 according to the units of measure.

#### 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 deenergized 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.

## 5.3 Temperature measurements

Temperature measurements are made to determine

a) Ambient temperature,
b) Temperature rise of certain parts of the motor above the ambient temperature when the motor is running at specified load,
c) Rapidly changing temperatures of certain parts of the motor, such as windings.

### 5.3.1 Methods of measuring temperature

Commonly used methods of temperature determination are defined in IEEE Std 1-1986, Table 2, and as follows:

a) Thermometer
b) Applied thermocouple
c) Contact thermocouple
d) Resistance
e) Embedded detector

Methods of measuring motor-winding temperature are described in IEEE Std 1-1986, IEEE Std 118-1978, and IEEE Std 119-1974. These methods can be classified into two categories according to their principle of operation. One category consists of methods employing a temperature-sensing element located in thermal contact with the windings. An applied thermocouple is an example of a sensing element used in this way. The other category includes those methods that sense the change of a physical property of the winding conductor material with temperature. The resistance method is based on a change of electrical resistivity with temperature and is an example of this category of methods.

### 5.3.2 Thermometer method

Liquid-in-glass thermometers should be examined for broken liquid columns before use. The thermometer bulb should be secured in position with a felt pad, a small piece of putty, or the equivalent, in such a manner as to shield it from the surrounding air. The thermometer bulb should not be higher than the stem. There should be no restriction of the natural windage of the motor or of the heat radiation from the coil being measured. The thermometer is applied to the hottest parts accessible without alteration of the structure.

The temperature shall be measured on the surface of the coil ends at two peripherally spaced locations.

Bimetallic, liquid-in-glass, and resistance thermometers are not recommended for use in measuring transient temperatures of motor windings. The size and shape of these thermometers make them difficult to apply to windings. Additionally, the large thermal capacity of these thermometers and the low thermal conductance from the windings may result in significant errors when measuring transient temperatures.

The thermometer method is usually not applied for measuring the temperatures in *small motors* because of the difficulties encountered in properly placing the thermometer.[8]

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[8] The term *small motor* is defined in ANSI/NEMA MG 1-1998, Section 1.

### 5.3.3 Applied thermocouple method

The applied thermocouple method is defined in IEEE Std 1-1986, 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 is deenergized. Hence the winding temperature reported should be the highest recorded value, which may be reached after the winding is deenergized.

#### 5.3.3.1 Selection of thermocouples

Iron-constantan thermocouples of 0.25 mm diameter 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.

Thermocouple wire used should be of known calibration.

#### 5.3.3.2 Method of application—general

The thermocouple junction may be soldered directly to the metallic conductor of the winding or held against the integrally applied insulation. For the latter, two basic methods of holding the thermocouple in position are by cementing and by means of securing with a felt pad tied to the windings. These three methods are discussed separately.

#### 5.3.3.3 Cemented

Using this method, the thermocouple is mechanically held against the winding by means of a cement. The cement used should not have a deleterious effect on the insulation. A commonly used cement is a mixture of fuller’s earth and water glass.

##### 5.3.3.3.1 Cemented—method of application

a) Because of the random buildup of varnish on motor windings and of the resulting variation of the thermal resistance between the thermocouple and the winding and the variation in temperature at different points of the winding, it is recommended that a number of thermocouples be applied to each energized motor winding under test to increase the probability of finding the hottest accessible area. Experience has shown that at least four thermocouples at each end of each energized winding are needed; and that the highest temperatures are usually obtained at the thinly varnished end.
b) The thermocouple junction should be in thermal contact with the integral insulation of the winding conductor.

c) The point of attachment of the thermocouple to the coil bundle is determined by visual examination. Experience has shown that the hottest accessible location on an induction motor winding is usually at the midpoint of the top winding bundle. The point of attachment should be away from any larger conductors or connecting wires and away from the stator iron. Massive items such as these tend to conduct heat away from the winding and to reduce the local temperature.

d) The preferred procedure is to place the thermocouple junction directly on top of a wire that is recessed between two adjacent wires in the bundle. The cement is then applied directly over the thermocouple junction, thereby cementing the junction in direct contact with the wire as well as having the cement bridge across the two adjacent wires.

e) The thermocouple junction should not be coated with any insulating material prior to attachment, as this not only increases its mass but decreases the thermal conductance between it and the winding conductor.

f) 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.

g) Care must be taken to ensure that the thermocouple junction is in direct contact with the integrally applied insulation of the conductor. There should be no cement between the thermocouple junction and the integrally applied insulation.

h) A sufficient length of time or temperature soaking should be allowed to drive off volatiles in the cement prior to testing. A fuller's earth and water glass mixture, when used as the cement, should be allowed to dry and be conditioned by being heated to the highest expected temperature before starting the test. About ten hours drying time at room temperature is usually sufficient.

i) The thermocouple lead wire should be tied against the motor windings a sufficient distance before being brought out in order to minimize the transfer of heat from the junction out through the thermocouple leads. For example, this may extend two to three inches or completely around the circumference of the windings, whichever is shorter.

#### 5.3.3.3.2 Cemented—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.

#### 5.3.3.3.3 Cemented—instrumentation

It is recommended that a self-balancing and continuously recording potentiometer be used. This is necessary to eliminate the error that results from the variable human element involved in reading manually balanced or indicating type meters. The potentiometer used should have a speed of response consistent with the expected rate of change in temperature of the winding being measured.

#### 5.3.3.3.4 Cemented—advantages

a) The small size of the thermocouple junction permits its location at many accessible parts of the winding.

b) It is relatively fast in its response to surrounding temperature as compared to thermometers.

c) It provides through its proper instrumentation a continuous record of winding temperature.

#### 5.3.3.3.5 Cemented—disadvantages

a) Thermal lag is inherent in surface-mounted thermocouples so that instantaneous peak temperature cannot be measured. The thermocouple reading continues to rise after the motor winding is deenergized so that a reading cannot be taken at the instant the winding is deenergized.

b) It is not possible to obtain hottest-spot temperatures since applied thermocouples give only accessible surface-winding temperature.
c) Repeatability of test results using this method is difficult due to the difference in subsequent mounting of thermocouples.
d) A number of thermocouples are required to obtain consistent results.
e) Drying out of volatiles in cement requires time so that motor testing is delayed until some time after thermocouples are applied.
f) There is a possibility of physical damage to the motor windings.

### 5.3.3.4 Felt pad

This method is similar to the cemented method, but differs in the manner by which the thermocouple junction is secured to the motor winding. Here the junction is mechanically held against the winding by being tied in position with suitable string after a square felt pad, approximately 6.4 mm square and 1.6 mm thick, is placed over the junction.

Method of application, range of usage, instrumentation, advantages, and disadvantages are the same as given for cemented thermocouples (5.3.3.3) except there is little likelihood of damaging windings and the drying time of cement is eliminated. However, the possibility exists of locating the thermocouple junction in a void in the winding and not measuring actual winding insulation temperature. Temperature values obtained generally are of the same level as with cemented thermocouples.

### 5.3.3.5 Soldered

This method requires the thermocouple junction to be attached directly to the metallic winding conductor by soldering. The composition of the solder should be such that the melting point is above the maximum temperature to be measured. A discontinuity in the heating or cooling curves usually indicates that a higher temperature solder should be used.

#### 5.3.3.5.1 Soldered—method of application

a) The point of attachment is selected visually in the same manner as described in 5.3.3.3.1(c). A number of thermocouples should be installed to increase the probability of finding the hottest accessible area. Experience has shown that higher temperature readings are generally obtained at the thinly varnished end and at the top coil bundles. Two thermocouples are generally needed at this preferred location.
b) The winding conductor is prepared by removing the insulation after a strand is loosened from the bundle. Suitable heat-insulating material is inserted behind the bared strand to protect the insulation of the remaining conductors during soldering. A thin application of solder is made to the conductor. The thermocouple junction, which has previously been formed by twisting and soldering, is placed across the conductor at the selected location and fused in place by applying heat from the soldering tip without adding any further solder. The junction should be attached at its first twist and any excess length should be cut off. The insulating barrier is then removed and the strand gently pushed back towards the bundle, scant of touching the insulated conductors.
c) The thermocouple lead wire should be tied against the windings in the same manner as in 5.3.3.3.1(i).

#### 5.3.3.5.2 Soldered—range of usage

The range of usage is the same as for cemented thermocouples (5.3.3.3.2) except as limited by the melting point of the solder used. Use of the correct type solder for the temperature range to be measured is necessary to avoid false readings.

#### 5.3.3.5.3 Soldered—instrumentation

The instrumentation is the same as for cemented thermocouples (5.3.3.3.3) with the added requirement that the instrument case, drive, and alternating-current balancing system be isolated electrically from the thermocouple circuit and from the alternating-current supply to the instrument so that the voltages picked up by the thermocouple will neither affect the instrument reading nor damage the instrument.

#### 5.3.3.5.4 Soldered—advantages

The advantages are the same as for cemented thermocouples (5.3.3.3.4). In addition, this method generally provides temperature readings of the same level or somewhat higher than the highest levels listed in 5.3.3.3. The temperature override of the junction is generally negligible and when present, indicates poor installation.

#### 5.3.3.5.5 Soldered—disadvantages

a) It is not possible to obtain the hottest spot temperature since soldered thermocouples give conductor temperature only at accessible points of measuring.
b) There is physical damage to the winding.
c) Electrical isolation of the measuring circuit is required.
d) The thermal characteristics of the conductor being measured may be different from the original coil bundle.
e) Repeatability of test results using this method is difficult due to differences in subsequent mountings of thermocouples.
f) A number of thermocouples is required to obtain consistent results.
g) Considerable skill and the proper choice of solder are required to avoid errors.

### 5.3.4 Contact thermocouple method

Contact thermocouple method, as defined in IEEE Std 1-1986, Table 2, "Consists in the determination of the temperature by the application of pointed prods, made of dissimilar metal, to an exposed bare-metal surface so that the metal whose temperature is to be measured forms part of a thermocouple circuit."

The standard references this method as suitable for measuring temperatures of bare-metal surfaces such as those of commutator bars and slip rings. This method is not normally used for measuring winding temperature.

#### 5.3.4.1 Resistance method

Resistance method, as defined in IEEE Std 1-1986, 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.

The principal methods of measuring winding resistance are voltmeter-ammeter or drop-of-potential, ohmmeter, Wheatstone bridge, and Kelvin double bridge.

The average temperature throughout a motor winding is often determined by comparing the resistance of the winding at the temperature to be determined with the resistance at a known temperature. Extreme care shall be taken to secure accurate resistance measurements because a small error will cause a comparatively large error in the calculated temperature. The cold resistance must be taken only after the motor has remained in a constant ambient long enough that the winding is at that ambient temperature. Resistance measurements shall be made as outlined in IEEE Std 119-1974. Equation (5.2), IEEE Std 118-1978, applies:

$$t_h = \frac{R_h}{R_c}(k + t_c) - k \tag{10}$$

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 225 for aluminum, based on a volume conductivity of 62%.

#### 5.3.4.1.1 Resistance—method of application

a) Cold resistance should be measured after the motor has been exposed to ambient temperature for a sufficient time for the entire motor to be at ambient temperature. The cold-winding temperature may then be measured by a reliable temperature measuring device.
b) For measurement after shutdown with rapidly varying temperature, the objective is to obtain the initial hot resistance reading 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.
c) When the circuit of an ac energized-motor winding is opened, a transient voltage momentarily appears. This transient is very low in magnitude and separate from any high-value transient induced by sudden opening of the circuit. Therefore, a means is required for taking the resistance measurement after a time delay to allow the low-value transient to disappear and not affect the reading. Using automatic instrumentation, the initial reading can be recorded within ten seconds thereby eliminating the need for extrapolating values to zero time.
d) Switching accomplished automatically involves electric contacts in the measuring circuit. Consideration of a contact resistance can be eliminated from the measurement with the drop-of-potential method using a potentiometer to obtain a null current balance. For the Wheatstone bridge or ohmmeter methods, contacts should be of low resistance and particularly of the type whose resistance will remain constant in the low-power circuit involved.
e) The same instrumentation should be used in taking the cold and hot measurements.
f) Any protective circuits in the motor should be bypassed to ensure the accuracy of resistance readings.

#### 5.3.4.1.2 Resistance—range of usage

The drop-of-potential method with readings by potentiometer may be used over the wide range of low- and high-resistance values found in small motor sizes. A Kelvin double bridge should be used for resistances below 1.0 Ω. The Wheatstone bridge method (using the three-lead type bridge) may be used for windings of cold resistance approximately 1.0 Ω and above. For windings of cold resistance of 5 Ω or higher, any of the methods in 5.3.4.1 may be used. Temperatures determined from resistance readings are stated in Equation (5.2), IEEE Std 118-1978 to apply for commercial grades of copper and aluminum conductors. The constant $k$ in Equation (10) provides results of the accuracy intended in this standard over a temperature range of 0 °C to 300 °C.

#### 5.3.4.1.3 Resistance—instrumentation

a) The use of self-balancing recording 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 potentiometer to record the voltage drop across the winding. With the current adjustable and suitable zero suppression on the potentiometer, the output may be calibrated to read temperature directly.

c) In the Wheatstone bridge method, a three-lead type bridge is recommended to eliminate lead resistance. The resistance of the contacts should be low and constant in value.

#### 5.3.4.1.4 Resistance—advantages

a) The resistance measurement method has an inherent advantage of rapid response and no thermal lag as compared to a sensing element such as a thermocouple. Hence, the thermal gradient error resulting from heat flow is eliminated.

b) Repeatability is inherent in this method so that good correlation of results can be obtained by different groups performing similar tests.

c) In many cases the motor may not require disassembly or more than removal of an end shield for lead connections. In these cases, there is little likelihood of damaging the winding and the motor may be placed on test immediately after connections are made.

#### 5.3.4.1.5 Resistance—disadvantages

a) This method measures only average conductor temperature.

b) Different means must be used for measuring the temperature of motor parts other than the winding.

c) An accurate determination of the cold resistance temperature value is required.

d) For other than the drop-of-potential method with potentiometer, errors may be introduced by changes in contact resistance of switching relays or at lead connections unless precautions are taken.

e) It may be necessary to change wiring connections of associated apparatus.

f) Some motors will require modification to permit connections to the winding.

### 5.3.5 Embedded-detector method

The embedded-detector method, as defined in IEEE Std 1-1986, subclause 1.14, “Consists in the determination of the temperature by thermocouples or resistance temperature detectors built into the machine, either permanently or for test purposes, in specified locations inaccessible to mercury or spirit thermometers.”

#### 5.3.5.1 Embedded detector—use

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.

#### 5.3.5.2 Embedded detector—limitations

This method does not lend itself for use on routine checks of winding temperature and also is not suitable for use on a motor already built, as provision for its use must be made at the time the motor stator is wound.

### 5.3.6 Temperature measurements—summary

a) For measurement of rapidly changing winding temperatures, two of the methods discussed, namely thermometer and contact thermocouple method, are not applicable.

b) With the applied thermocouple method, repeatability of test results requires care in applying the thermocouple and requires that a sufficient number of thermocouples be used.

c) For determination of hot-spot temperature, the embedded-detector method is recommended.

d) The resistance method is capable of good correlation of results by different groups performing similar tests.

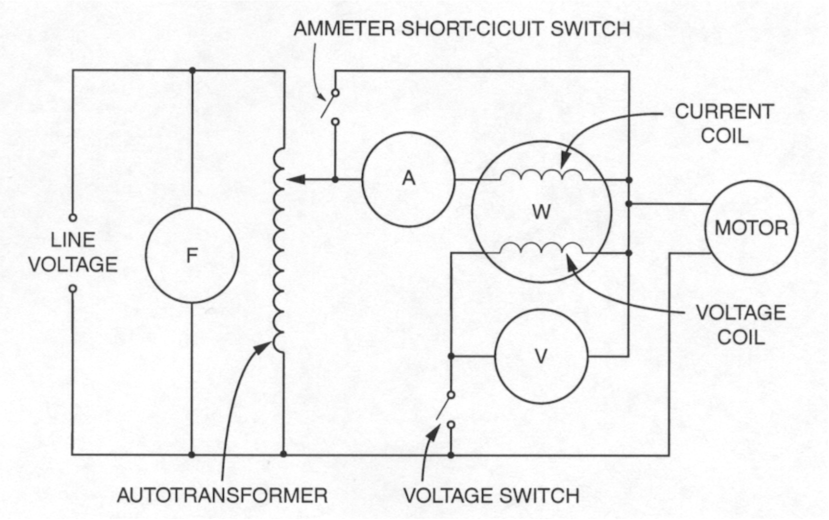
e) The soldered thermocouple method is not generally used for verification testing as it damages the winding insulation. It is essentially a research tool that may be used for special investigation.

# 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.



A = ammeter V = voltmeter
F = frequency meter W = wattmeter

**Figure 2—Variable voltage test connections**

### 6.1.2 Ambient temperature

All performance determinations should be obtained with an ambient temperature of 25 °C. However, the ambient temperature 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 tests outlined in this standard. All tests 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 Stator resistive loss

The resistive loss of a stator winding, $P_{sl}$, is given by

$$P_{sl} = \frac{I^2 R}{2} \tag{11}$$

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 5.1.5.1.1).

### 7.1.1 Specified temperature

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

a) The temperature rise determined by resistance measurement from a rated load temperature test plus 25 °C (see Clause 10). Rated load is the rating identified on the nameplate at 1.0 service factor.
b) The temperature determined in (a) for a motor of the same construction and electrical design.
c) 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 (°C) |
|---|---|
| A | 75 |
| B | 95 |
| F | 115 |
| H | 130 |

## 7.2 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).

### 7.2.1 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 some fixed interval, such as 100 r/min, or by measurement of the change in speed for a fixed time interval. The friction and windage loss, $P_f$, is calculated from the speed and the rate of deceleration by Equation (12):

$$P_f = knJ\left(\frac{dn}{dt}\right) \tag{12}$$

where

$k$ is a constant selected according to the units of measure, $k$ is $109.7 \times 10^4$ 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 in (r/min · second).

When this method is applied to small motors, it is recommended that the speed be measured by visual means.

### 7.2.2 Dynamometer method

One method of determining the friction and windage loss is to measure the torque required to drive the rotating parts at normal speed by means of a dynamometer. The friction and windage loss, $P_f$, is then expressed in watts as

$$P_f = \frac{T_f n}{k} \tag{13}$$

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).

The dynamometer used for this test should be such that the measured friction and windage torque, $T_f$, represents at least 15% of the normal torque capacity of the dynamometer.

### 7.2.3 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 is accomplished preferably by a variable-voltage transformer. 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 (14).

$$P_l = \frac{I_s^2}{2}\left(R_t + \frac{P_1}{I_1^2}\right) \tag{14}$$

where

$P_1$ 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 (14).

#### 7.2.3.1 No-load current

The current at no load is measured directly.

### 7.3 Rotor resistive loss

When slip can be accurately determined, the rotor resistive loss, $P_{rl}$, should be determined for slip, $s$ (see 5.2.3). In the case of wound-rotors, the rotor resistive loss includes the brush-contact loss (see 7.6). The rotor resistive loss is given by

$$P_{rl} = (P_0 - P_{sl} - P_{cl} - P_f)s \tag{15}$$

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 (15) then reduces to

$$P_{rl} = P_0 - P_{sl} - P_{cl} \tag{16}$$

### 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 7.2) from the sum of friction and windage loss and core loss.

## 7.5 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.

### 7.5.1 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.

### 7.5.2 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 (17).

$$P_{sll} = (P_r - P_f) - P_{sl} \tag{17}$$

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).

#### 7.5.2.1 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 to an equation of the form

$$P_i = A_i I^{N_i} \tag{18}$$

where

$i$ is 1, 2, or 3;
$P_i$ $P_1 = P_{sll}$, $P_2 = (P_r - P_f)$, 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.

### 7.5.3 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 load.

For other than rated load, it shall be assumed that the stray-load loss, $\tilde{P}_{sll}$, is proportional to the square of the rotor current, i.e.,

$$\tilde{P}_{sll} = P_{sll}\left(\frac{\bar{I}}{I_0}\right)^2 \tag{19}$$

where

$P_{sll}$ is the assumed value of stray-load loss at rated load (W);
$\tilde{I}$ is the value of rotor current at the load point (A);
$I_0$ is the value of rotor current at rated load (A).

## 7.6 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, $E$, is the ratio of output power, $P_{out}$, to input power, $P_{in}$ as illustrated in Equation (20).

$$E = \frac{P_{out}}{P_{in}} \tag{20}$$

Alternatively, since output power is equal to the input power minus the total loss, the efficiency may also be determined by Equation (21).

$$E = \frac{P_{in} - P_l}{P_{in}} \tag{21}$$

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 temperature. A dynamometer correction is also made, if applicable (see 5.2.4.2.1).

### 8.2.1 Test procedure

The motor is loaded by means of a mechanical brake or dynamometer (see 5.2.4).

Unless otherwise specified, the efficiency shall be determined at rated voltage, frequency, and temperature rise or actual temperature rise as determined by heat run. If a curve of efficiency versus output power is to be plotted, a minimum of seven points is recommended: readings of electrical power, current, voltage, frequency, slip, torque, ambient temperature, and stator winding temperature or stator winding resistance should be obtained for at least four load points substantially equally spaced between 25% load and 100% load, and two load points suitably chosen above 100% load, but not to exceed 150% load.

### 8.2.2 Calculation form

Motor efficiency shall be determined as outlined in Form 3 (see A.3). The stator resistive loss is to be corrected for temperature as indicated in Form 3. Dynamometer correction should be made, if applicable (see 5.2.4.2.1). 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*, to the product of voltage, *V*, and current, *I*, as illustrated in Equation (22).

$$PF = \frac{P}{VI} \tag{22}$$

All instruments should be read as simultaneously as practical.

# 9. Performance tests

## 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 3.

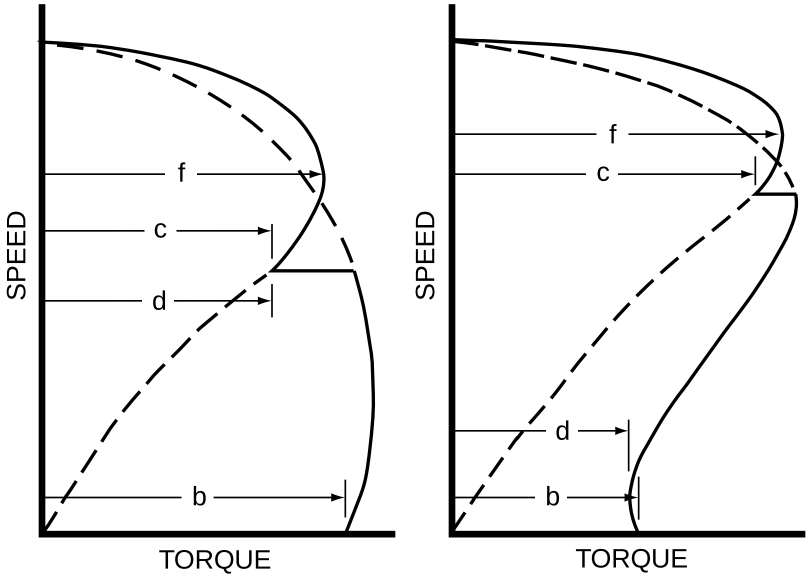
### 9.1.2 Speed-current characteristic

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 3—Representative speed-torque characteristic curves of single-phase induction motors**

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

Methods 1 and 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 (23), as follows:

$$T = \frac{k(P_o + P_l)}{n} \tag{23}$$

where

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

### 9.2.1.2 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 (24) as follows:

$$T = \left(\frac{J}{k}\right)\left(\frac{dn}{dt}\right) \tag{24}$$

where

$T$ is the torque (N · m);
$\frac{dn}{dt}$ is the acceleration (r/min · seconds);
$J$ is the rotational moment of inertia (kg · m$^2$)
$k$ is $109.7 \times 10^{-4}$ 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 5.2.2.1).

### 9.2.1.3 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 (25):

$$T = \frac{k}{n}(P_i - P_l) - T_{fw} \tag{25}$$

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).

#### 9.2.1.4 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 seconds.

The motor temperature at the start of every test shall be not less than 10 °C nor greater than 40 °C, unless otherwise agreed to by the purchaser and manufacturer. The motor temperature should not exceed the rated temperature rise plus 40 °C.

## 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.

The motor temperature at the start of every test shall be not less than 10 °C nor greater than 40 °C, unless otherwise agreed to by the purchaser and manufacturer. The motor temperature should not exceed the rated temperature rise plus 40 °C.

## 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.

The pull-up torque should be determined with the motor operating as close as possible to its normal operating temperatures, unless otherwise agreed to by the purchaser and manufacturer (see IEEE Std 119-1974 for temperature corrections).

### 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 3.

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.

The switching torque should be determined with the motor operating as close as possible to its normal operating temperatures, unless otherwise agreed to by the purchaser and manufacturer (see IEEE Std 119-1974 for temperature corrections).

### 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.

The breakdown torque should be determined with the motor operating as close as possible to its normal operating temperatures, unless otherwise agreed to by the purchaser and manufacturer (see IEEE Std 119-1974 for temperature corrections).

### 9.8 Pull-in torque

Pull-in torque applies to synchronous motors only and is the maximum constant external torque under which the motor will pull its connected inertia load into synchronism. The pull-in torque is obtained at rated voltage and frequency. Because the inertia of the connected load, which is often unknown, greatly affects the pull-in torque, the pull-in torque is defined in this procedure as that pull-in torque measured with no appreciable external inertia.

A brake may be used to measure the pull-in torque, but a dynamometer should not be used.

If the inertia of the load is known and can be simulated on test, the pull-in torque may also be measured under this condition if it is so desired.

The pull-in torque should be determined with the motor operating as close as possible to its normal operating temperatures, unless otherwise agreed to by the purchaser and manufacturer (see IEEE Std 119-1974 for temperature corrections).

### 9.9 Pull-out torque

Pull-out torque applies to synchronous motors only and is the maximum torque provided during synchronous operation. The pull-out torque is obtained at rated voltage and frequency. The pull-out torque may be determined by allowing the motor to run light in synchronism and then gradually increasing the load until the motor pulls out of synchronism.

The pull-out torque should be determined with the motor operating as close as possible to its normal operating temperatures, unless otherwise agreed to by the purchaser and manufacturer (see IEEE Std 119-1974 for temperature corrections).

## 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. The following subclauses describe 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 °C and 40 °C 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 raise 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 °C of the ambient temperature, unless otherwise specified.

#### 10.3.1.2 Permissible overloading

When testing motors rated for continuous operation, loads ranging between 125% and 150% of rated load are permissible during the preliminary heating period in order to shorten the time of test.

#### 10.3.1.3 Termination of test

When testing motors rated for continuous operation, temperature readings shall be taken at intervals not to exceed 30 minutes for *medium motors* and not to exceed 15 minutes for *small motors*.[9] The temperature test shall continue until the change in temperature between two successive readings is 1 °C 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 thermometers are used, they should be preheated to nearly the expected temperature.

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

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[9] The terms *small motor* and *medium motor* are defined in ANSI/NEMA MG 1-1998, Section 1.

If the initial resistance reading cannot be made within 30 seconds after power is switched off, it shall be made as soon as possible, and resistance readings shall be taken at intervals of 30 seconds to 60 seconds 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 seconds. A semilogarithmic plot is recommended, in which resistance is plotted on the logarithmic scale. The value of resistance thus obtained shall be considered as the resistance.

#### 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 Temperature of rotors and other parts

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

### 10.3.3 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. Liquid-in-glass thermometers or thermocouples may be used.

### 10.3.4 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.
c) *Lubricant.* It is customary to measure the temperature of oil lubricants. The temperatures of oil in the reservoirs should be taken.

## 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:

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.

### 10.4.2 Instrumentation—general

Errors of considerable magnitude can result from the manual reading and recording of changing temperatures on manual instruments or on automatic instruments of the indicating type. For this reason, it is recommended that automatic balancing and continuous recording instruments be used. The recording instrument should have a speed of response fast enough to follow closely the changing temperature.

# 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

The high-potential test voltage shall be successively applied between each electric circuit and the frame or core. All other metal parts, including other circuits and windings, shall be connected to the frame or core. No leads shall be left unconnected during the test because such a condition may produce an extremely severe strain on windings connected to those leads. In making the test, the voltage shall be increased to full value as rapidly as is consistent with correct voltmeter indication, and the full voltage shall be maintained for one minute. The voltage should then be reduced, in not more than 15 seconds, to 25% or less of the full value. Motors produced in large quantities should be subjected to 20% excess voltage for 1 second (see ANSI/NEMA MG1-1998).

Capacitors of capacitor-type motors must be left connected to the windings in a normal manner.

In making these tests, care should be taken to impress only the desired test voltage. A sudden application of the test voltage may cause a dangerous over-voltage. One method of overcoming this difficulty is the use of a variable resistor in the primary circuit of the test transformer. The resistor may be cut out after the potential has been applied. An alternative method is the use of a suitable choke in the primary of the test transformer to limit the possible surges. It is possible to inadvertently obtain over-voltages on the motor through a resonant or partially resonant condition between the capacitance of the winding to ground and the leakage reactance of the testing transformer. To obtain most accurate results, the test voltage should be measured by a direct-reading electrostatic voltmeter or by an oscilloscope. More details on the dielectric test are available in IEEE Std 4-1995.

**CAUTION**

In the interests of safety, precautions should be taken to prevent anyone from coming in contact with any part of the circuit or apparatus while high-potential tests are in progress. High-potential tests should be conducted only by trained personnel, and adequate safety precautions should be taken to avoid injury to personnel and damage to property. Tested windings should be discharged carefully to avoid injury to personnel on contact.

## 11.3 Noise

See IEEE Std 85-1973.

## 11.4 Vibration

Both horizontal and vertical vibration measurements shall be made at the motor bearing housing. The double amplitude on either end in either direction is to be taken as the measure of vibration.

Mounting arrangements will affect the vibration of a motor. In order that measurements may be obtained independent of mounting methods as nearly as possible, the motor shall be placed on flexible mountings or pads. These pads or springs shall compress by the weight of the motor alone in amounts not less than the values shown in Table 3.

**Table 3—Spring compression**

| Speed (r/min) | Minimum compression (mm) |
|---|---|
| 900 | 25.4 |
| 1200 | 14.3 |
| 1500 | 9.5 |
| 1800 | 6.4 |
| 3600 | 1.6 |
| 7200 | 0.4 |

The pads or springs shall be so selected that their compression is not more than one-half the original thickness.

## 11.5 Overspeed

Overspeed tests are rarely made on induction motors. If such a test is specified, every precaution shall be taken to protect personnel and equipment.

# Annex A

(normative)

# Typical forms

## 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 (medium 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

| | |
|---|---|
| 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

## 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 Manufacture | | Voltage (V) | |
| Type | | Full-Load Current (A) | |
| Frame | | Locked-Rotor Current (A) | |
| Power (W) | | Design Letter (medium 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<br>Resistance<br>Thermometer<br>Thermocouple** | **(Cross out two) by<br>Resistance<br>Thermometer<br>Thermocouple** |
| Hours Run | Voltage (V) | Current (A) | Cooling Air (°C) | | |
| | | | | | |
| | | | | | |
| | | | | | |

Method of testing (cross out two) A B C

### Performance Characteristics

| **Full-Load Slip** | **No-Load Current (A)** | **Resistance at 25 °C (Ω)** | **Breakdown Torque (Cross out three)<br>N · m<br>ozf · in<br>ozf · ft<br>lbf · ft<br>_____%V** | **Locked-Rotor Torque (Cross out three)<br>N · m<br>ozf · in<br>ozf · ft<br>lbf · ft<br>_____%V** | **Locked-Rotor Current (A)<br>____%V** | **High-Potential Test Voltage<br>Start Windings<br>Run Windings** |
|---|---|---|---|---|---|---|
| | | **Start Windings___<br>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 Form 3: Determination of motor efficiency

### 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 (medium 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

| Item | Description | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|---|
| 1 | Ambient Temperature (°C) | | | | | | |
| 2 | Stator Winding Temperature $t_t$ (°C) | | | | | | |
| 3 | Frequency (Hz) | | | | | | |
| 4 | Slip Speed (r/min) | | | | | | |
| 5 | Corrected Slip Speed (r/min) | | | | | | |
| 6 | Speed (r/min) | | | | | | |
| 7 | Torque (N · m) | | | | | | |
| 8 | Dynamometer Correction (N · m) | | | | | | |
| 9 | Corrected Torque (N · m) | | | | | | |
| 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 (%) | | | | | | |

Performance Curve______________________

### Summary of Characteristics

| | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| Load (% of rated) | | | | | | |
| Power Factor (%) | | | | | | |
| Efficiency (%) | | | | | | |
| Speed (r/min) | | | | | | |
| Line Current (A) | | | | | | |

### A.3.1 Explanatory notes—form 3, test data

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.
6) Speed, see 5.2.2.
7) Measured torque, see 5.2.1 for other units of measure.
8) Dynamometer correction, see 5.2.4.2.1.
9) The corrected torque is equal to (7) + (8).
10) Output power is equal to [(6)(9)] / 9.549, see 5.2.4.
11) Voltage, see 5.2.1.
12) Stator current, see 5.1.3.
13) Input power, see 5.1.4.
14) The stator resistive loss at $t_t$.
15) The stator resistive loss at the specified temperature for resistance correction, $t_s$, see 7.1.1.
16) The correction to input power is equal to (15) – (14).
17) The corrected input power is equal to (13) + (16).
18) Percent power factor is equal to 100(13) / [(11)(12)], see 8.3.
19) Percent efficiency is equal to 100(10) / (17), see 8.1.

# Annex B

(informative)

# Bibliography

IEEE 100™, *The Authoritative Dictionary of IEEE Standards Terms*, Seventh Edition.[10]

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[10] IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA (http://standards.ieee.org/).