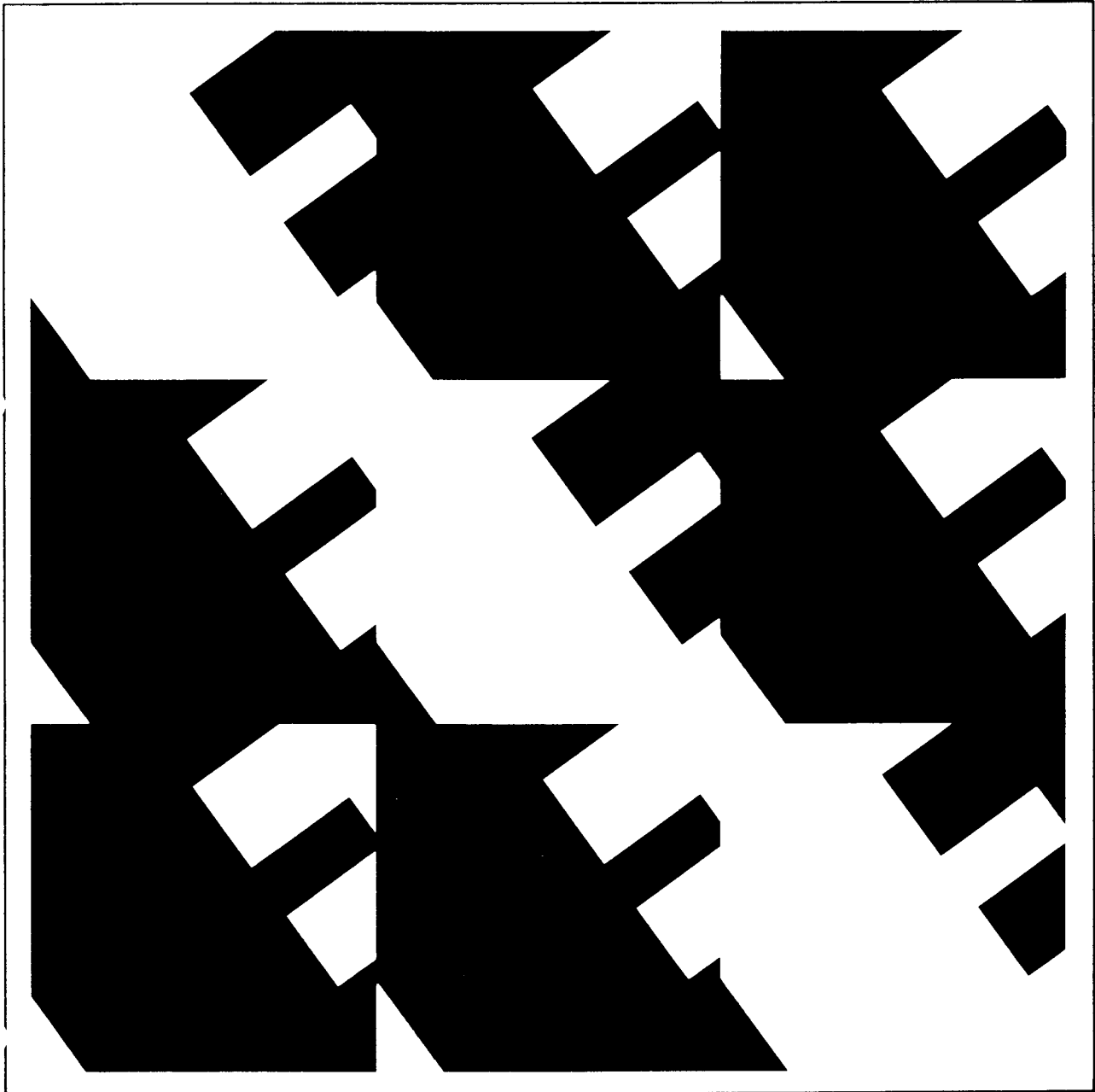


IEEE Standard Test Procedure for Polyphase Induction Motors and Generators



ANSI/IEEE Std 112-1984



Published by The Institute of Electrical and Electronics Engineers, Inc 345 East 47th Street, New York, NY 10017, USA

January 20, 1984

SH09258

**ANSI/IEEE
Std 112-1984
(Revision of
ANSI/IEEE Std 112-1978)**

An American National Standard
**IEEE Standard Test Procedure for
Polyphase Induction Motors and Generators**

Sponsor
**Rotating Machinery Committee
of the
IEEE Power Engineering Society**

Approved December 9, 1982
IEEE Standards Board

Approved June 26, 1985
American National Standards Institute

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Foreword

(This Foreword is not a part of IEEE Std 112-1984, IEEE Standard Test Procedure for Polyphase Induction Motors and Generators.)

This standard is a revision of IEEE Std 112-1978, IEEE Standard for Polyphase Induction Motors and Generators.

The Institute wishes to acknowledge its indebtedness to those who have so freely given of their time and knowledge and have conducted experimental work on which many of its publications are based.

At the time this standard was approved, the membership of the working group of the Induction Machinery Subcommittee was:

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IEEE Standard Test Procedure for Polyphase Induction Motors and Generators

1. Scope

This standard covers instructions for conducting and reporting the more generally applicable and acceptable tests to determine the performance characteristics of polyphase induction motors and generators. The tests described may be applied to both motors and generators, as needed. Additional tests, not specified herein, may be required to satisfy specific research or application needs. These procedures shall not be interpreted as requiring the making of any specific test in a given transaction.

2. References

- [1] AIEE Committee Report, Stray Load Loss Measurement in Induction Machines. *AIEE Transactions*, vol 78, pt III A, pp 67-71, April, 1959.
- [2] ANSI/IEEE Std 4-1978, IEEE Standard Techniques for High-Voltage Testing.
- [3] ANSI/IEEE Std 43-1974 (R1979), IEEE Recommended Practice for Testing Insulation Resistance of Rotating Machinery.
- [4] ANSI/IEEE Std 100-1977, IEEE Standard Dictionary of Electrical and Electronics Terms.
- [5] ANSI/NEMA MG1-1978,¹ Motors and Generators.
- [6] IEEE Std 1-1969, IEEE General Principles for Temperature Limits in the Rating of Electric Equipment.

¹ ANSI documents are available from the Sales Office, American National Standards Institute, 1430 Broadway, New York, NY, 10018. Copies of this standard are also available from the National Electrical Manufacturers Association, 2101 L Street, NW, Washington, DC 20037.

[7] IEEE Std 62-1978, IEEE Guide for Field Testing Power Apparatus Insulation.

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

[9] IEEE Std 118-1978, IEEE Standard Test Code for Resistance Measurement.

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

[11] IEEE Std 120-1955 (R1972), IEEE Master Test Code for Electrical Measurements in Power Circuits.

[12] Morgan, T. H., Brown, W. E., and Schumer, A. J. Reverse-Rotation Test for the Determination of Stray Load Loss in Induction Machines. *Transactions of the American Institute of Electrical Engineers*, vol 58, pp 319-322, July, 1939.

3. Tests — General

3.1 Kinds of Tests. Polyphase induction machines are normally given a routine test, but may be given additional tests.

For typical routine tests refer to ANSI/NEMA MG1-1978 [5],² parts 12 and 20.

A typical form for reporting routine test data is shown in Section 8, Form A-1. A typical form for reporting additional test data is shown in Section 8, Form A-2.

3.2 Choice of Tests. A complete list of the tests covered by this standard is given in the Table of Contents. Alternate methods are described

² The numbers in brackets correspond to those of the references listed in Section 2 of this standard.

for making many of the tests, suitable for different sizes and types of machines and different conditions. In some cases, the preferred method is indicated.

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

3.3 Use of this Standard. After the method of test is chosen, all necessary data may be obtained by following the instructions and precautions given only in those subsections which contain, in their left-hand margins, the letter designating the method selected. For example: when testing by Method B, reference need be made only to the paragraphs opposite the letter "B" or the word "All," which will be employed to designate subsections common to all methods. Many of these subsections include alternate methods for obtaining the necessary data. Unless otherwise specified, the manufacturer may choose the method best suited to the facilities available in such cases.

3.4 Precautions During Test. Since the performance of an induction machine is dependent not only upon the value of voltage and frequency but also on the wave shape and the balance in magnitude and phase angle of the voltages, correct data can be obtained only by careful measurement and by employing a suitable source of power. (See 4.1.1.)

4. Electrical Measurements

4.1 (All). All quantities are root-mean-square values unless otherwise indicated.

4.1.1 (All) Power Supply. The source of supply shall closely approach sine waveform and shall provide balanced phase voltages. The voltage waveform deviation factor³ shall not exceed 10%. The frequency shall be main-

³ The deviation factor of a wave is the ratio of the maximum difference between corresponding ordinates of the wave and of the equivalent sine wave to the maximum ordinate of the equivalent sine wave when the waves are superposed in such a way as to make this maximum difference as small as possible. The equivalent sine wave is defined as having the same frequency and the same root-mean-square value as the wave being tested.

tained within $\pm 0.5\%$ of the value required for the test being conducted, unless otherwise specified.

4.1.2 (A-B-C). Rapid changes in frequency cannot be tolerated on input-output tests, as such variations are transmitted to the output-measuring devices. Any departure from assumed frequency directly affects the efficiency obtained by Methods A or B. For these methods, the frequency shall be measured (or known to be) within 0.5% of the specified test value.

4.2 (All) Instrument Selection. The instruments used in electrical measurements shall be selected to give indications well up on the scale, that is, where a fraction of a division is easily estimated and where such a fraction is a small percentage of the value read.⁴

4.3 (All) 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.⁴

4.4 (All) Voltage. The phase voltages shall be read at the motor terminals. Tests may be made where the voltage unbalance does not exceed $\pm 0.5\%$. The percent voltage unbalance equals 100 times the maximum voltage deviation from the average voltage divided by the average voltage.

EXAMPLE: With voltages of 220, 215, and 210 the average is 215, the maximum deviation from the average is 5, and the percent unbalance equals $100 \cdot \frac{5}{215} = 2.3\%$.

4.5 (All) Current. The line currents to each phase of the motor shall be measured. If the line currents are unequal, the arithmetic average value shall be used in calculating machine performance from the test data.

4.6 (All) Power. Power input to a three-phase machine may be measured by two single-phase wattmeters connected as in the two-wattmeter method, one polyphase wattmeter, or three single-phase wattmeters. The total power read on a wattmeter shall be reduced by the amount of the I^2R loss in the voltage circuits of the instruments whenever this loss is a measurable portion of the total power read.

⁴ Further information regarding the use of instruments is given in IEEE Std 120-1955 (R1972) [11].

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

5. Performance Determination

5.1 (All) Resistance Measurements

5.1.1 Reference Resistance. To obtain direct-current resistance measurements of stator (and rotor in the case of wound-rotor machines), the procedures given in IEEE Std 118-1978 [9] should be used.

5.1.2 Reference Ambient. All performance determination shall be corrected to an ambient temperature of 25 °C.

5.1.3 Correction to a Specified Temperature. When the resistance R_t of a winding has been determined by test at winding temperature t_t , the resistance may be corrected to a specified temperature t_s by Eq 1.

$$R_s = R_t \left(\frac{t_s + k}{t_t + k} \right) \text{ ohms} \quad (\text{Eq 1})$$

where

- R_s = winding resistance, corrected to specified temperature t_s , ohms
- t_s = specified temperature, degrees Celsius
- R_t = test value of winding resistance, ohms
- t_t = temperature of winding when resistance was measured, degrees Celsius
- k = 234.5 for pure copper
- = 225 for aluminum based on a volume conductivity of 62%

NOTE: For other winding materials, a suitable value of k must be used.

5.2 (All) Efficiency. Efficiency is the ratio of output power to input power. The electrical power is measured directly; the mechanical power may be measured directly, or obtained by adding the losses to the electrical power for generator action, or subtracting the losses from the electrical power for motor action. Unless otherwise specified, the efficiency shall be determined for rated voltage and frequency.

5.2.1 (All) Measurement of Input and Out-

put. Direct measurements of input and output are always made on fractional-horsepower machines and generally on small machines, but such measurements become increasingly difficult with the equipment usually available as the size of the machine increases.

5.2.1.1 In general, the brake (Method A) or dynamometer (Method B) method is used on fractional-horsepower machines and the dynamometer method on machines up to about 500 hp at 1800 r/min or equivalent rated torque at other speeds. For larger machines, the pump-back method (Method C) may be used whenever duplicate machines are available. The segregated-loss method (Method E or Method F) is also used for larger machines. In all methods, the precautions listed in 4.1 to 4.6 shall be observed.

5.2.1.2 (A-B) Bearing Loss Stabilization. Some motors may experience a change in efficiency until the bearings reach a stabilized operating condition. Stabilization can be considered to have occurred whenever the power input at no-load (or coupled to a de-energized dynamometer) does not vary by more than 3% under either of the following conditions:

- (1) Two successive readings at half-hour intervals
- (2) One reading prior to and one reading following the efficiency test

5.2.2 (A-B-C) Direct Measurement Methods. In all direct measurement method tests the electrical and mechanical power are measured directly. The difference between the various methods lies in the manner of measuring mechanical power.

5.2.2.1 (A-B) Measurements. Readings of electrical power, current, voltage, frequency, slip, torque, ambient temperature, and stator winding temperature, or stator winding resistance, shall be obtained for six load points substantially equally spaced from one-quarter to one and one-half times rated load.

5.2.2.2 (A-B-C) Determination of Motor Performance. When motor performance is tested using direct measurement methods, it is determined as outlined in Section 8, Form B or Form E, or both. Unless otherwise specified, horizontal, polyphase squirrel-cage motors rated 1 hp to 125 hp shall be tested by dynamometer (Method B). Vertical motors in this horsepower range shall also be tested by Method B if the bearing construction permits. If the bearing construction does not permit

the use of a dynamometer, vertical motors in this horsepower range may be tested by any of the other specified methods. Polyphase motors larger than 125 hp may be tested by dynamometer (Method B), or any of the other specified methods.

5.2.2.3 (A) Method A: Brake. The motor is loaded by means of a mechanical brake which is capable of being adjusted to provide the desired torque loading. Care shall be exercised in the construction and use of the brake and brake pulley. The "tare," if present, shall be carefully determined and compensated for. Performance of a machine shall be calculated as shown in Section 8, Form B.

5.2.2.4 (B) Method B: Dynamometer.⁵ Another method of measuring mechanical power of an induction machine is by loading the machine with a dynamometer. The power in kilowatts is obtained from Eq 2.

$$\text{power in kilowatts} = \frac{T \cdot n}{k} \quad (\text{Eq 2})$$

where

T = torque

n = rotational speed in r/min

k = 9549 if T is in N·m

= 7043 if T is in lb·ft

To obtain accurate results the dynamometer rating shall not exceed three times the machine rating, and it shall be sensitive to a torque of 0.25% of the rated torque. The dynamometer correction shall be made as outlined in Section 8, Form B.

The steps described in items (1)-(4) shall be followed and are a specific means of maximizing the accuracy of the dynamometer test. The method requires that data be taken for at least six approximately equally spaced load points between 25% and 150% of rated load.

All data is taken with the machine operating as a motor or as a generator, depending upon the region of operation for which efficiency data is required. The apparent total loss (input-output) is segregated with stray load loss defined as the apparent total loss minus conventional loss (that is, the sum of stator and rotor I^2R loss, core loss, and friction and windage loss). The value of stray load loss thus determined is plotted versus torque squared, a

⁵ A dynamometer is defined as a load absorber equipped with means for indicating torque and speed and is not limited to a cradle base construction.

linear regression analysis is used to reduce the effect of random error in the test measurements, and the smoothed data is used to calculate the final value of efficiency.

(1) For each load point, measure the input kilowatts and output power, and calculate the apparent total loss by subtracting the measured output from the measured input.

(2) The stray load loss shall be separately calculated for each load point by subtracting from the apparent total loss the stator I^2R loss at the temperature of the test, the core loss, friction and windage loss, and the rotor I^2R loss corresponding to the measured value of slip. The stray load loss shall be calculated for six approximately equally spaced load points between 25% and 150% of rated load.

(3) Smooth the stray load loss data by using a linear regression analysis.

$$W_{LL} = AT^2 + B \quad (\text{Eq 3})$$

where

W_{LL} = stray load loss as plotted versus torque squared

T = torque

A = slope

B = intercept

If the slope is negative or if the correlation factor r is less than 0.9, delete the worst point and recalculate A and B . If this increases r to 0.9 or larger, use the second calculation; if not, the test is unsatisfactory. Errors in the instrumentation or test readings, or both, are investigated. The source of the error should be investigated, corrected, and the test repeated. The smoothed value of stray load loss is:

$$W_{LLc} = AT^2 \quad (\text{Eq 4})$$

(4) Calculate motor efficiency using Section 8, Form E, which includes temperature correction. Use W_{LLc} appropriate to the load point.

Bearing friction or measurement errors, or both, may cause torque readings to differ for the same value of electrical power, depending upon whether the load is increasing or decreasing prior to reading. When a correlation factor r equal to or larger than 0.9 is not obtained after the second calculation, the average of two sets of readings shall be taken. The first set shall be taken while gradually increasing the load; the second set while decreasing the load, care being taken in each case not to overrun the points to be read. Curves of torque versus electrical power shall be plotted for each set

of readings, and the average of the curves shall be used.

5.2.2.5 (C) Method C: Duplicate Machines. This method of determining efficiency may be used when duplicate machines are available. The two machines are coupled together and electrically connected to two sources of power, the frequency of one being adjustable. One machine is operated as a motor at rated voltage and frequency, and the other is driven as a generator at rated voltage per Hertz, but at lower frequency, to produce the desired load.

5.2.2.5.1 Readings shall be taken of the electrical input and output, stator winding temperature or stator winding resistance, and slip of each machine. The test shall be repeated with the direction of power flow reversed. The frequency of the first machine remains unchanged while that of the second is raised to produce the desired load. The location of the instruments and instrument transformers shall not be changed.

5.2.2.5.2 By this reversal of power flow ordinary calibration errors of all instruments are minimized. Phase-angle errors of the instrument transformers are cumulative for motoring and generating tests. It is important to make accurate corrections for these phase-angle errors, since they will make the losses appear smaller than the true value. See 4.3.

5.2.2.5.3 The stray load loss is obtained as follows:

(1) The stator I^2R loss at the temperature of the test is calculated for each machine, using the observed currents.

(2) The motor rotor I^2R loss is:

Motor slip ·

$$\text{(Motor input - Stator } I^2R \text{ loss - Core loss)} \quad \text{(Eq 5)}$$

using the observed motor slip in per-unit of synchronous speed.

(3) The generator rotor I^2R loss is:

Generator slip ·

$$\text{(Generator output + Stator } I^2R \text{ loss + Core loss)} \quad \text{(Eq 6)}$$

using the observed generator slip in per-unit of synchronous speed.

(4) The combined stray load loss is determined by subtracting from the total measured loss (the difference between input and output) the sum of the stator I^2R losses, rotor I^2R

losses, core losses, and friction and windage losses of the two machines.

(5) The stray load losses are assumed to be proportional to the square of the rotor current. The stray load losses are taken as

Motor stray load loss =

$$\frac{\text{Motor rotor } I^2R \text{ loss} \cdot \text{Combined stray load loss}}{\text{Motor rotor } I^2R \text{ loss} + \text{Generator rotor } I^2R \text{ loss}} \quad \text{(Eq 7)}$$

Generator stray load loss =

$$\text{Combined stray load loss} - \text{Motor stray load loss} \quad \text{(Eq 8)}$$

The average of the results obtained with the two directions of power flow shall be taken as the correct value of stray load loss.

5.2.2.5.4 The efficiency is then taken as

Motor efficiency, in percent =

$$\frac{\text{Electrical input} - \text{Total motor losses}}{\text{Electrical input}} \cdot 100 \quad \text{(Eq 9)}$$

Generator efficiency, in percent =

$$\frac{\text{Electrical output}}{\text{Electrical output} + \text{Total generator losses}} \cdot 100 \quad \text{(Eq 10)}$$

Total losses equal the sum of the stator and rotor I^2R losses corrected to the specified temperature for resistance correction, core loss, friction and windage losses, and stray load loss.

When the rated load temperature rise has not been measured, the resistance of the windings shall be corrected to the following temperature:

Class of Insulation System	Temperature (°C)
A	75
B	95
F	115
H	130

This reference temperature shall be used for determining I^2R losses at all loads. If the rated temperature rise is specified as that of a lower class of insulation system, the temperature for resistance correction shall be that of the lower insulation class.

Refer to Section 8, Form E for a detailed workup of results.

5.2.3 (E-F) Segregated-Loss Methods. The input shall be measured as outlined in Method E or calculated as described in Method F. The output shall be determined by subtracting the losses from the input. The losses of an induction machine are:

Type of Loss	Description
(a) Friction and windage	Mechanical loss due to bearing (and brush) friction, and windage
(b) Core	Loss in iron at no load
(c) Stator I^2R	I^2R loss in stator windings
(d) Rotor I^2R	I^2R loss in rotor windings (and brush-contact loss of wound-rotor machines)
(e) Stray load	Stray loss in iron and eddy-current losses in conductors

5.2.3.1 (E) Method E: Input Measurements.

To obtain required data, it is necessary to couple, belt, or gear the machine to a variable load. The same arrangement as used for the temperature test may be employed.

The required data are:

stator resistance	power input ⁶
no-load current and no-load losses	line current ⁶ terminal voltage ⁶
rotor slip ⁶	stray load loss

For tabulating and calculating the performance, Section 8, Form E is recommended. All necessary explanatory notes are included in the form.

The stator winding resistance for each load point can be estimated by comparing the temperature rise measured by an embedded temperature detector or a temperature sensor located on the stator coil end or the air outlet temperature rise, with corresponding temperature rise measurements obtained as steady-state values during a temperature test.

⁶ These values shall be obtained for six load points ranging from one-quarter to one and one-half times full load. Alternatively, a single load point may be combined with Method F to determine performance at other load points. See 5.2.3.2.5.

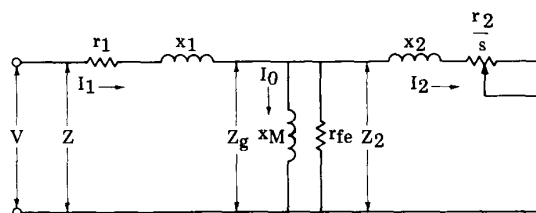


Fig 1
Equivalent Circuit

5.2.3.2 (F) Method F: Equivalent Circuit Calculations. When tests under load are not made, operating characteristics (efficiency, power factor, torque, etc) are calculated from the no-load and impedance data by the equivalent circuit (see Fig 1). Required constants are calculated using equations in Section 8, Form F-1 and may be recorded on Form F-2. A work sheet upon which the circuit calculations may be made is found in Section 8, Form F-3.

5.2.3.2.1 Values of constants determined from the foregoing equations and test data may be entered in Section 8, Form F-2.

5.2.3.2.2 The results of the calculations of Section 8, Form F-3 may be plotted in curve form from which the summary of characteristics in Section 8, Form F-2 can be determined, or reiterative calculations can be made to determine the slip corresponding to the desired load points for Section 8, Form F-2.

5.2.3.2.3 Accurate predictions of machine characteristics by the equivalent circuit will depend upon the closeness by which r_2 represents the actual rotor resistance to currents of low frequency. A most careful procedure during the low-frequency impedance test is imperative. An alternate method of obtaining r_2 is described in 5.2.3.2.5.

5.2.3.2.4 Section 8, Form F-1 is arranged on the basis of x_1 and x_2 remaining constant throughout the range of operation of the machine. Should the curve of current versus voltage depart from a straight line in the range of currents under consideration, each column of calculations in Section 8, Form F-3 shall use values of reactance obtained from this curve for the value of I_1 calculated in the column.

5.2.3.2.5 When a slip-current point under load with stator winding temperature of t_t is available, Method F may be used to determine machine characteristics at other loads. In such cases, r_2 is not determined from the low-

frequency impedance test. The following procedure is used:

Use Section 8, Form F-3, starting with line 2, with assumed value of r_2/s and value of r_1 based on stator winding temperature of t_t . After reaching line 21, check calculated value of input watts versus measured value of input watts. Adjust assumed value of r_2/s , and reiterate until calculated value of input watts agrees with measured value of input watts, within 1%.⁷

Obtain r_2 by multiplication of the final assumed value of r_2/s by the measured value of slip in per unit of synchronous speed. The procedure establishes the value of r_2 (without temperature correction) to be used in calculating the load performance characteristics.

Correct r_1 and r_2 to the specified temperature t_s in accordance with Eq 1.

Determine performance at desired load points following the format shown in Section 8, Form F-3.

5.2.3.2.6 Maximum or breakdown torque as a motor is determined from Section 8, Form F-3 using slip value

$$s = \frac{r_2}{\sqrt{r_1^2 + (x_1 + x_2)^2}} \quad (\text{Eq 11})$$

5.3 Losses

5.3.1 (All) Stator I^2R Loss. The stator I^2R loss (in watts) is equal to

- 1.5 I^2R for 3-phase
- 2.0 I^2R for 2-phase

where

I = measured or calculated rms current per terminal at the specified load

R = direct-current resistance between any two line terminals corrected to a specified temperature (see 5.1.1)

⁷ In some cases, it may be desirable to adjust the equivalent circuit values to agree with the measured line current as well as the measured slip and input watts from a rated load tested point, prior to determining the performance at other points (that is $\frac{3}{4}$ load, $\frac{1}{2}$ load, etc).

The procedure is to adjust r_2/s and x_M until the calculated value of input watts and input current both agree with the measured value of input watts and input line current within 1%. Other circuit parameters should not be adjusted. Obtain r_2 by multiplication of the final assumed value of r_2/s by the measured value of slip in per unit of synchronous speed. Correct r_1 and r_2 to the specified temperature t_s in accordance with 5.1.3, and determine performance at desired load points following the format shown in Section 8, Form F-3.

The specified temperature used in making resistance corrections (see 5.2.2.5.4) shall be determined by one of the following, listed in order of preference.

(1) Measured temperature rise by resistance from a rated load temperature test plus 25 °C.

(2) Specified temperature given in an applicable product standard, such as ANSI/NEMA MG1-1978.

5.3.2 (All) Rotor I^2R Loss. The rotor I^2R loss, including brush-contact losses for wound-rotor machines, shall be determined from the slip whenever the latter is accurately determinable, using Eqs 12 or 13.

$$\text{Motor rotor } I^2R \text{ loss} = (\text{Measured stator input} - \text{Stator } I^2R \text{ loss} - \text{Core loss}) \cdot \text{Slip} \quad (\text{Eq 12})$$

where the slip is in per unit of synchronous speed.

$$\text{Generator rotor } I^2R \text{ loss} = (\text{Measured stator output} + \text{Stator } I^2R \text{ loss} + \text{Core loss}) \cdot \text{Slip} \quad (\text{Eq 13})$$

where the slip is in per unit of synchronous speed.

5.3.3 (All) Core Loss and Friction and Windage Losses. Refer to 5.6.2 for information on the determination of the core loss and friction and windage losses.

5.3.4 (C-E-F) Stray Load Loss. The stray load loss is that portion of the total loss in a machine not accounted for by the sum of friction and windage, stator I^2R loss, rotor I^2R loss, and no-load core loss.

5.3.4.1 (C-F) Indirect Measurement. The total stray load loss may be determined by measuring the total losses and subtracting from these the sum of the friction, windage, and core loss, stator I^2R loss, and rotor I^2R loss.

For other load points, the stray load losses are assumed to be proportional to the square of the rotor current.

5.3.4.2 (E-F) Direct Measurement [1]. The stray load loss occurring at fundamental frequency may be determined by applying balanced polyphase current to the stator-winding terminals with the rotor removed. The electrical input minus the stator I^2R loss at test resistance is equal to the fundamental frequency stray load loss. During the test, bearing brackets and other structural parts in which the current might be induced shall be in place. The current used in making

this test and the test described in 5.3.4.2.1 shall be identified as I_t and have magnitudes covering the range of values established by Eq 16 for loads ranging from one-quarter to one and one-half times rated load.

5.3.4.2.1 The stray load loss occurring at high frequencies may be determined by a reverse-rotation test [12]. With the motor completely assembled, balanced polyphase voltage is applied at the stator-winding terminals. The rotor is driven by external means at exactly synchronous speed in the direction opposite to the stator field rotation. (The correct speed may be easily determined by stroboscopic methods or a digital tachometer.) The electrical input to the stator winding is measured.

5.3.4.2.2 The mechanical power required to drive the rotor shall be measured both with and without current applied to the stator-winding terminals. For wound-rotor motors, the rotor terminals shall be short-circuited.

5.3.4.2.3 The stray load losses shall be calculated as follows:

$$\text{stray load loss} = LL_s + LL_r \quad (\text{Eq 14})$$

In Eq 14, the values of LL_s and LL_r are for the same value of stator-winding current I_t where:

LL_s = W_s - the stator-winding I^2R loss. The stator winding I^2R loss shall be the product of the number of phases, I_t^2 , and r_1 taken at each load point

$LL_r = (P_r - P_f) - (W_r - LL_s$ - stator-winding I^2R loss). The stator-winding I^2R loss shall be the product of the number of phases, I_t^2 , and r_1 taken at each load point

LL_s = fundamental-frequency stray load loss

LL_r = higher frequencies stray load loss

r_1 = stator phase resistance. For a three-phase machine this is taken as one-half of the resistance between terminals

P_r = mechanical power required to drive rotor with voltage applied at stator-winding terminals

P_f = mechanical power required to drive rotor without voltage being applied at stator-winding terminals

W_s = electrical input to stator winding with rotor removed

W_r = electrical input to stator winding during reverse-rotation test.

NOTES: (1) The suggested practice is to plot separately test values of LL_r and LL_s versus stator-winding current I_t . From these curves, values of LL_s and LL_r for the same stator-winding current, I_t , can be read. If the data are accurate, each curve will conform to a square-law relationship between power and current.

(2) The low-power factors encountered during the tests specified in 5.3.4.2 through 5.3.4.2.3 make it imperative that phase-error corrections be applied to all wattmeter readings. Refer to IEEE Std 120-1955 (R1972) [11].

(3) During the reverse rotation portion of the test, resistance may be measured with the test motor still rotating at or near synchronous speed by using a low-resistance switch to connect the resistance meter to the winding as soon as the supply voltage is removed. The measurement of the resistance of one phase is sufficient.

5.3.4.3 (E-F) Alternate 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 ammeters included to read the stator current. The rotor is driven by external means at synchronous speed. The rotor excitation is adjusted until the current circulating in the stator winding has the value for which a stray load loss determination is desired. The mechanical power required to drive the rotor, both with (P_r) and without (P_f) rotor excitation is measured

$$\text{stray load loss} = P_r - P_f - \text{stator-winding } I^2R \text{ loss at temperature during test} \quad (\text{Eq 15})$$

5.3.4.4 (E-F) Stray Load Loss Value. The method of determining stray load loss at various load points is described in 5.3.4.4.1 and 5.3.4.4.2.

5.3.4.4.1 (E). The stray load loss of a machine operating normally with a stator line current I is taken as the value of stray load loss as determined in 5.3.4.2.3 or 5.3.4.3 for a value of current equal to

$$I_t = \sqrt{I^2 - I_0^2} \quad (\text{Eq 16})$$

I_t = value of stator-winding current during stray-load-loss test

I_0 = value of no-load current

I = operating value of stator line current for which stray load loss is to be determined

The value of stray load loss in Section 8, Form F-2 shall correspond to a value of I_t corresponding to the rated value of stator line current I .

5.3.4.4.2 (F). The value of stray load loss

is assumed to be proportional to the square of the secondary current. The value of stray load loss in Section 8, Form F-2 shall correspond to an equivalent value of I_s equal to the value of secondary current at rated load.

5.4 Slip

5.4.1 (A-B-C-E). The slip shall be measured for the range of load for which the efficiency is determined. Analog tachometers or speed counters are not sufficiently accurate for the measurement of slip; therefore, stroboscopic or digital tachometer methods are recommended.

5.4.2 (All). Slip measurements shall be corrected to the specified stator temperature as follows:

$$S = s \left(\frac{t_s + k}{t_t + k} \right) \quad (\text{Eq 17})$$

$k = 234.5$ for copper

$= 225$ for aluminum based on a volume conductivity of 62%

$S =$ slip corrected to standardized stator temperature t_s

$s =$ slip measured at stator-winding temperature t_t

$t_s =$ specified temperature for resistance correction (see 5.3.1)

$t_t =$ observed stator-winding temperature during load test

5.5, (All) Power Factor. The power factor is the ratio of watts to volt amperes.

Power Factor for

$$\text{three-phase} = \frac{\text{watts}}{\text{line volts} \cdot \text{line amperes} \cdot 1.732} \quad (\text{Eq 18})$$

$$\text{two-phase} = \frac{\text{watts}}{\text{phase volts} \cdot \text{phase amperes} \cdot 2} \quad (\text{Eq 19})$$

5.5.1 (All) Directly Obtained. For three-phase machines the power factor may be checked by Eq 20 when the two-wattmeter method is used.

$$\text{power factor} = \frac{1}{\sqrt{1 + 3 \left(\frac{W_1 - W_2}{W_1 + W_2} \right)^2}} \quad (\text{Eq 20})$$

where

$W_1 =$ the higher reading

$W_2 =$ the lower reading

If W_2 gives a negative reading, it must be considered a minus quantity.

If a polyphase wattmeter is used, the values of the single-phase wattmeter readings shall be obtained by opening separately each of the voltage-coil circuits of the polyphase wattmeter. With pulsating loads, the power factor obtained by the second method may be higher than that obtained by the first method. The higher value shall be taken as the correct reading. The difference is due to the inclusion in the volt-amperes of the pulsating component of current which is a function of the load rather than of the machine itself. The power factor determined from the ratio of wattmeter readings is not affected by the presence of pulsating current.

5.5.2 (F) Equivalent-Circuit Calculation. The power factor may be determined from the equivalent circuit by dividing the total resistance by the total impedance. This determination is shown in Section 8, Form F-3, line 31.

5.6 (C-E-F) Tests With No Load. The test with no load is made by running the machine at rated voltage and frequency without connected load. To ensure that the correct value of friction loss is obtained, the machine shall be operated until the input becomes constant. (See 5.2.1.2.)

5.6.1 (C-E-F) Current. Read the current in each line. This current is the "no-load" current.

5.6.2 (C-E-F) Losses. The reading of input power is the total of the losses in the motor at no-load. Subtracting the stator I^2R loss (at the temperature of this test) from the input gives the sum of the friction (including brush-friction loss on wound-rotor motors) and windage and core losses.

Separation of the core loss from the friction and windage loss may be made by reading voltage, current, and power input at rated frequency and at voltages ranging from 125% of rated voltage down to the point where further voltage reduction increases the current.

A curve of power input versus voltage is plotted and the curve so obtained is extended to zero voltage. The intercept with zero voltage axis is the friction and windage loss. The intercept may be determined more accurately if the input is plotted against the voltage squared for values in the lower voltage range. An example is the dashed curve shown in Fig 2.

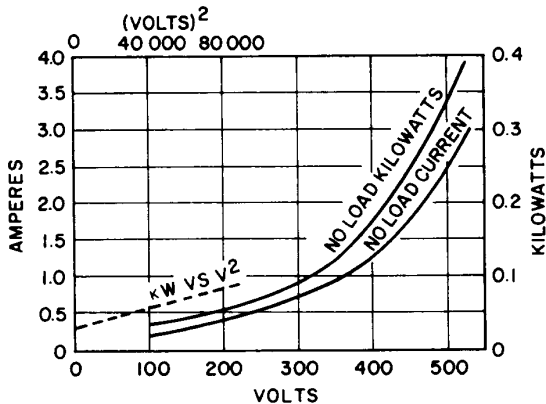


Fig 2
Extrapolation of No-Load Kilowatts
to Zero Voltage

5.7 (All) Tests With Load. Tests with load are made for determination of efficiency, power factor, speed, and temperature rise. Some of the miscellaneous tests outlined in Section 7 are also made with load. For all tests with load the machine shall be properly aligned and securely fastened. For readings to be used in performance determinations, the machine temperature rise shall be some value between 50% and 100% of rated temperature rise. The usual procedure is to take readings at higher loads first and follow with readings at lower loads.

5.8 (All) Tests With Rotor Locked. It should be recognized that the testing of induction machines under locked-rotor conditions with polyphase power involves high mechanical stresses and high rates of heating. Therefore, it is necessary that:

- (1) The mechanical means of locking the rotor be of adequate strength to prevent possible injury to personnel or damage to equipment.
- (2) The direction of rotation be established prior to this test.
- (3) The machine be at approximately ambient temperature before the test is started. The current and torque readings shall be taken as quickly as possible, and, to obtain representative values, the machine temperature should not exceed rated temperature rise plus 40 °C. The readings for any point shall be taken within 5 s after the power is applied for motors rated 10 hp and below and within 10 s for all motors above 10 hp rating.

5.8.1 (All) Current. This test may be taken either as a check of quality or to determine performance. When possible, readings shall be taken at rated voltage and frequency, since the current is not directly proportional to the voltage because of changes in reactance caused by saturation of the leakage paths.

When the test is made to check the quality of squirrel-cage machines, it is possible to omit the mechanical means of locking the rotor by applying single-phase power of rated voltage and frequency to only one phase of a two-phase machine or between any two of the machine line terminals of a three-phase machine. With a three-phase machine, the line current will be approximately 86% and the power input will be approximately 50% of the corresponding values obtained with polyphase power. The values so obtained may be compared with those measured on a duplicate unit which was subjected to a complete test.

5.8.2 (All) Torque. The locked-rotor torque is taken as the minimum torque developed at rest in all angular positions of the rotor. The torque may be measured with a rope and pulley, or with a brake or beam. Wound-rotor motors and synchronous reluctance motors are always subject to variations in locked-rotor torque, depending on the angular position of the rotor with respect to the stator. For squirrel-cage motors it is usual practice to lock the rotor in any convenient position. If the locked-rotor torque is not measured directly as mentioned above, the approximate locked-rotor torque may be calculated as follows:

$$T = \frac{k(P_{SI} - P_{CU} - P_C)c_1}{n_s} \quad (\text{Eq 21})$$

where

- P_{SI} = input power to stator, kW
- P_{CU} = stator I^2R loss⁸ in kilowatts at the test current (refer to 5.3.1)
- P_C = core loss in kilowatts at test voltage (refer to 5.3.3)
- n_s = synchronous speed, r/min
- c_1 = a reduction factor (varying between 0.9 and 1.0) to account for nonfundamental losses
- $k = 9549$ for T in N·m
- $= 7043$ for T in lb·ft

⁸ At the temperature of the locked rotor test.

5.8.3 (All) Power. Readings of watts input shall be taken simultaneously with those of current and torque.

5.8.4 (F) Impedance. When the motor performance is to be determined by the equivalent circuit method, impedance curves are required. These consist of readings of voltage, current, and power input, with the rotor blocked and short-circuited, the frequency of the applied voltage being constant.

5.8.4.1 It is necessary that the impedance data be evaluated at reduced frequency in order to obtain values of rotor resistance and total reactance required for use in the performance calculation by Method F. The impedance data shall be determined from one of the following:

(1) Three-phase locked-rotor impedance test at maximum of 25% of rated frequency and at rated current.⁹

(2) Three-phase locked-rotor impedance, total reactance, and secondary resistance curves based on tests at rated frequency, approximately 50% of rated frequency, and a maximum of 25% of rated frequency, all at rated current. This curve shall be used to determine the value of total reactance and rotor resistance at operating frequency.⁹

(3) Values of rotor resistance and total reactance at reduced frequency can be obtained from readings (volts, watts, amperes, slip, and stator resistance) taken at (or near) the breakdown point or at some slip speed approximating the desired reduced rotor frequency. For this method, the voltage should be reduced to give approximately full-load current at the chosen slip point, and the slip must be measured carefully.

(4) When none of the above methods is practical, the following may be utilized: three-phase locked-rotor impedance test at rated frequency with the total reactance corrected for frequency based on calculations or tests on a similar machine and r_2 determined by a load point as outlined in 5.2.3.2.5.

⁹ The total reactance of the machine for use in the performance calculation by Section 8, Method F is determined from the reactance determined at reduced frequency by multiplying the low-frequency value by the ratio of the rated frequency to the low frequency. In general, the reactance so determined will be larger than when directly measured at normal frequency, the difference being small for single-squirrel-cage rotors and relatively large for double-squirrel-cage or deep-bar rotors.

5.8.4.2 The reactance shall be measured at rated-load current, because the effect of saturation may materially reduce the reactance at higher currents. It is important that the value of reactance used in equivalent circuit calculation is not reduced by saturation and deep-bar effect, otherwise, the calculated power factor will be found to be higher than the true value.

5.8.4.3 The rotor of a squirrel-cage motor is a symmetrical bar winding; therefore, the impedance of the motor is practically the same for any position of the rotor relative to the stator. In wound-rotor motors and in synchronous reluctance motors, the impedance varies with different positions of the rotor relative to the stator. It is, therefore, necessary to determine the rotor positions at which the impedance is maximum and minimum so that the rotor may be blocked on an average position for impedance curves. For accomplishing this, the current variation with rotor position shall be observed. Before taking readings on wound-rotor machines the rotor shall be short-circuited.

The angular distance through which it is necessary to observe the current variation shall be determined by allowing the rotor to revolve slowly and observing the stator current, noting the distance the rotor must move for the stator current to complete a cycle. For machines having an integral number of slots per pole per phase in both rotor and stator, this distance will be equal to one-half of a pole pitch for two-phase machines and two-thirds of a pole pitch for three-phase machines. For wound-rotor machines, especially those having fractional-slot windings, this angular distance may be as much as a full pole pitch. The rotor shall be blocked so that it cannot move and the impressed voltage shall be increased gradually until a current of approximately rated value is obtained. Voltage and current on all phases shall be read and recorded, and the voltage in the different phases shall be balanced. Holding the same voltage, the rotor shall be turned slowly and the minimum and maximum values of current during a complete cycle recorded. The rotor shall then be blocked for the impedance test on the position which gives a current equal to the average of the minimum and maximum values previously recorded.

5.8.4.4 Having blocked the rotor in any convenient position in the case of a squirrel-

cage machine, or in an average position as determined above in the case of wound-rotor machines, or synchronous reluctance motors, the impedance curve may be taken. Simultaneous readings of voltage and current in all phases and of power input shall be taken at several points, establishing the values with special care in the neighborhood of full-load current. The stator-winding temperature or stator-winding resistance shall also be recorded. Care shall be taken not to overheat the windings. Taking the highest readings first and the lower readings in succession will help to equalize the temperature.

Curves shall be plotted, using volts as abscissas, with amperes and the algebraic sum of the wattmeter readings as ordinates. The volt-ampere curve is usually a straight line, curving slightly upward at the higher values. On closed-slot rotors, however, there is also a distinct curve upward at low voltages.

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

5.9 (All) Tests for Speed Torque and Speed Current

5.9.1 General

5.9.1.1 The speed-torque characteristic is the relation between torque and speed, embracing the range from zero to synchronous speed. This relation, when expressed as a curve, will include maximum (breakdown), pull-up, and locked-rotor torques.

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

5.9.2 Speed-Torque Curve. Any one of the following methods may be used to obtain data for a speed-torque curve. The selection of the method will depend upon the size and the speed-torque characteristics of the machine and the testing facilities. In all four methods, sufficient test points should be recorded to ensure that reliable curves, including irregularities, can be drawn in the regions of interest from the test data. It is important that the frequen-

cy of the power supply be maintained constant throughout the test at the rated value for the motor.

Methods 1 and 4 require the maintenance of constant speed for each reading. Therefore, they cannot be used in regions where the torque of the machine increases with speed more rapidly than that of the loading device.

From the results of the following tests, adjusted to rated voltage, curves of torque and current should be plotted versus speed.

5.9.2.1 Method 1. Measured Output. A direct-current generator which has had its losses previously determined is coupled or belted to the motor being tested. An alternating-current power supply of rated frequency is connected to the motor terminals. The voltage should be as high as can be impressed upon the motor terminals without excessive heating, at least 50% of rated voltage, if possible. The speed of the motor for each test point is controlled by varying the load on the generator.

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

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

The total power output of the motor is the sum of the output and losses of the direct-current generator.

The torque, T , at each speed is calculated using Eq 22.

$$T = \frac{k(P_{GO} + P_{GL})}{n} \quad (\text{Eq 22})$$

where

P_{GO} = output of direct-current generator, kW
 P_{GL} = losses of direct-current generator (including friction and windage), kW

n = test speed of motor, r/min

k = 7043 for T in lb-ft

= 9549 for T in N-m

At the speed for the test point, the torque and current of the motor are adjusted to the specified voltage, V , as described in 5.9.2.5.

5.9.2.2 Method 2. Acceleration. In the acceleration method the motor is started with no load and the value of acceleration is determined at various speeds. The torque at each speed is determined from the acceleration of the mass of the rotating parts. Accurate measurements of speed and acceleration are an essential requirement of this method. The motor should be operated from a rated-frequency alternating-current power source.

The rate of acceleration to be used and, consequently, the duration of the test are determined by the type of instruments which are used to make the measurements. In any case, the accelerating time should be long enough so that electrical transient effects in the instruments and in the motor do not distort the speed-torque curve. The accelerating time must also be long enough to permit recording the necessary number of mechanical and electrical measurements with sufficient accuracy for plotting the required curves (see 5.9.2).

When suitable automatic data acquisition systems or high-speed recorders are available, this test can be conducted with rapid acceleration consistent with the above limits. The torque at each point can be obtained by Eq 23.

If indicating instruments are used, the accelerating time should be increased by using a lower applied voltage or coupling an inertia to the motor shaft to permit manual recording of the required data at each point.

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

If Method 3 (5.9.2.3) is to be used as a check, line power with a polyphase wattmeter or two single-phase wattmeters should be taken at each speed point where data are recorded.

It may sometimes be necessary to take more than one run at different voltages in order to

get satisfactory readings throughout the curve, especially when there are appreciable cusps in the speed-torque characteristics.

The torque, T , at each speed is calculated from the acceleration using Eq 23.

$$T = \frac{J}{k} \left(\frac{dn}{dt} \right) \quad (\text{Eq 23})$$

where

(English System)

T = torque, lb·ft

J = moment of inertia of rotating parts, lb·ft²

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

$k = 307.2$

(SI - MKS System)

T = torque, N·m

J = moment of inertia of rotating parts, kg·m²

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

$k = 9.549$

At the speed for the test point, the torque and current of the motor are corrected to the specified voltage, V , as described in 5.9.2.5.

5.9.2.3 Method 3. Input. In this method, the torque is determined by subtracting the losses in the machine from the input power. It is a valuable check on the other methods, and is particularly useful when the machine cannot be unloaded to determined torque by acceleration. In practice, the method is approximate because the stator losses cannot be readily determined for the actual operating conditions and must be approximated. This method is also subject to error in the case of special machines which may have substantial positive or negative harmonic torques that are not readily evaluated.

The machine is started as described in 5.9.2.2 except that it does not have to be unloaded. The input readings called for in 5.9.2.2 are plotted against the speed readings. The line voltage, line current, power, and speed should be plotted versus time. Average values of the zero-speed readings from the locked test, as described in 5.8.2, adjusted to the voltage at which the other readings were taken, should be included.

The torque, T , at each speed is determined from the input power using Eq 24.

$$T = \frac{k \left[P_{SI} - P_{CU} - P_C - LL_s - LL_r \left(\frac{n}{n_s} \right)^{0.5} \right]}{n_s} - T_{FW} \quad (\text{Eq 24})$$

where

- P_{SI} = input power to stator, kW
- P_{CU} = stator I^2R loss in kilowatts at the test current (refer to 5.3.1)
- P_C = core loss in kilowatts at test voltage (refer to 5.3.3)
- LL_s = fundamental-frequency stray load loss in kilowatts at the test current (refer to 5.3.4.2.3)¹⁰
- LL_r = high-frequency stray load loss in kilowatts at the test current (refer to 5.3.4.2.3)¹⁰
- n = test speed, r/min
- n_s = synchronous speed, r/min
- k = 7043 for T in lb·ft
= 9549 for T in N·m
- T_{FW} = motor friction and windage torque at test speed, lb·ft or N·m.

At the speed for the test point, the torque and current of the motor are corrected to the specified voltage, V , as described in 5.9.2.5.

5.9.2.4 Method 4. Direct Measurement. The torque and current are measured as the machine is loaded at various speeds with a dynamometer or prony brake. At each speed, simultaneous readings of voltage, current, speed, and torque are taken. The test should be taken as near rated voltage as practical but, if a reduced voltage is used, the motor torque and current should be corrected to the specified voltage as described in 5.9.2.5.

5.9.2.5 Correction for Speed-Torque and Speed-Current Curves for Tests run at Reduced Voltage. When it is necessary to establish values of current and torque at rated voltage, based on tests made at reduced voltage, it should be recognized that, because of saturation of the leakage flux paths, the current may increase by a ratio somewhat greater than the first power

¹⁰ If the LL_s component of stray load loss is not available it may be assumed that the stray load loss is equal to LL_r .

If the stray load loss ($LL_s + LL_r$) has been determined from a dynamometer test or a pump-back test, the total value of stray load loss may be used as the value of LL_r or the value of LL_s may be determined by the method outlined in 5.3.4.2 and LL_r determined as the value of stray load loss minus the value of LL_s .

of the voltage, and the torque by a ratio somewhat greater than the square of the voltage. The relationship varies with design; however, as a first approximation, the current is calculated as varying directly with voltage, and torque with the square of voltage.

A more exact method of test requires determining the rate of change of current and torque with voltage by establishing speed-torque and speed-current curves for at least two, and preferably for three or more values of voltage.

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

6. Temperature Test

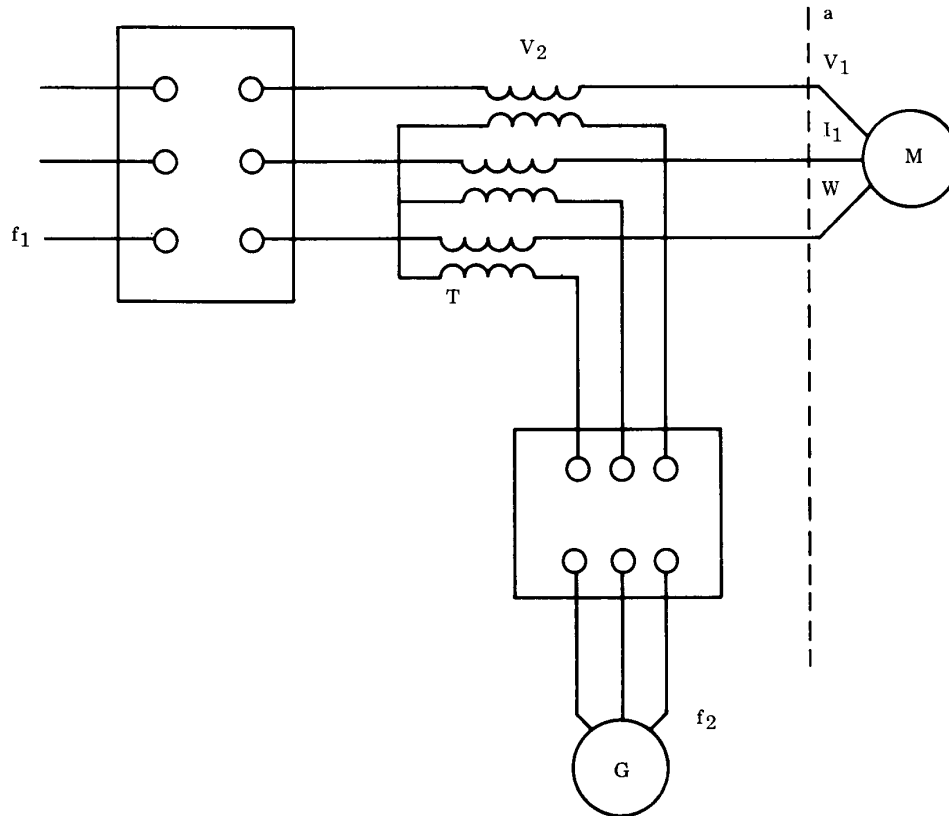
6.1 Purpose. Temperature tests are made to determine the temperature rise of certain parts of the machine above the ambient temperature, when running under a specified loading condition. The following subsections are guides for the test procedure and treatment of data.

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

6.2.1 Temperature measuring devices shall be in accordance with IEEE Std 119-1974 [10]. At the start of the temperature test all instruments shall be checked to make certain that there are no appreciable instrument errors or stray-field effects.

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

6.2.3 The loading method for making the temperature test shall be one of the following:
(1) The actual loading method in which the



M = motor to be tested
 T = series transformer
 a = connecting points of voltmeter, ammeter, and wattmeter
 G = auxiliary power generator
 V_1 = terminal voltage (rated voltage)

f_1 = frequency (rated frequency)
 I_1 = primary current of induction machine
 V_2 = auxiliary voltage
 f_2 = auxiliary frequency
 W = input power

NOTES: (1) The phase rotation of the auxiliary power shall be chosen to have the same direction as that of the main power.

(2) V_2 will be less than V_1 (usually 10%-20% of V_1). V_2 is the voltage necessary to cause rated current I_1 to flow.

Fig 3
Typical Connection for
Superposed Equivalent Loading

machine is loaded as a motor or generator under the rated (or desired) condition.

(2) Primary — superposed equivalent loading method. A typical connection is shown in Fig 3. The machine to be tested is operated at no-load from a main power source and a low-voltage auxiliary power of different frequency is superposed.

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

NOTES: (1) When the loading for the temperature test is the superposed equivalent loading method per 6.2.3 (2), the slip measurement per 5.4 does not apply and a tested value of rotor I^2R loss cannot be obtained.

Therefore, when equivalent loading is used, calculated rotor I^2R must be used in calculating efficiency by the segregated loss method, 5.2.3.

(2) Inasmuch as there are oscillatory torques applied to the stator and rotor of the machine supplied with power at two different frequencies per 6.2.3(2), vibration will be abnormal during this condition and normal criteria for vibration do not apply. Vibration should be monitored and compared against acceptable limits for the machine being tested. After the machine has been heated as described under 6.2.3(2), the auxiliary frequency can be removed and vibration measured with rated frequency and voltage applied to determine the vibration of the machine operating at normal running temperature. The machine will cool rapidly after removing the auxiliary frequency. Therefore, temperature should be monitored by thermocouple, to ensure that vibration is measured while the motor is within $\pm 25\%$ of normal operating temperature.

6.3 Methods of Measuring Temperatures

6.3.1 There are four methods of determining temperatures:

- (1) Thermometer
- (2) Embedded detector
- (3) Winding resistance
- (4) Local temperature detector

For general information, refer to IEEE Std 119-1974 [10], and IEEE Std 1-1969 [6].

6.3.1.1 Method 1. Thermometer. This method is the determination of temperature by mercury or alcohol thermometers, by resistance thermometers, or by thermocouples, with any of these instruments applied to the hottest part of the machine which is accessible to mercury or alcohol thermometers.

6.3.1.2 Method 2. Embedded Detector. This method is the determination of temperature by thermocouples or resistance thermometers built into the machine.

Specially designed instruments should be used with resistance thermometers to prevent the introduction of significant error or damage due to heating of the resistance thermometer during measurement. Many ordinary resistance measuring devices may not be suitable because of the relatively large current which may be passed through the resistance element while making the measurement.

6.3.1.3 Method 3. Resistance. This method is the determination of temperature by comparing the resistance of the winding at the temperature to be determined with the resistance at a known temperature. The temperature of the winding is calculated by following the equation:

$$t_t = t_b + \left(\frac{R_t - R_b}{R_b} \right) (t_b + k) \quad (\text{Eq 25})$$

where

- t_t = total temperature of winding when R_t was measured, °C
- R_t = resistance measured during test, Ω
- R_b = reference value of resistance previously measured at known temperature t_b , Ω
- t_b = temperature of winding when reference value of resistance R_b was measured, °C
- k = 234.5 for pure copper
= 225 for aluminum based on a volume conductivity of 62%

Since a small error in measuring resistance will make a comparatively large error in determining temperature, the winding resistance should be measured by a double bridge or other means of equivalent accuracy, and checked by a second instrument if possible.

In a squirrel-cage machine, the change in rotor resistance due to heating results in a change in slip. For a given value of torque, the temperature of the rotor can be indirectly determined from the hot slip reading s_h , and cold slip reading s_c , by substituting s_h for R_t and s_c for R_b in Eq 25. The slip shall be accurately determined for both hot and cold conditions. Small errors in the slip values may occasion considerable errors in the calculated temperature from which the temperature rise is obtained.

6.3.1.4 Method 4. Local Temperature Detector. The local temperature of various parts of a machine can be determined using a local temperature detector. The maximum dimension of the detecting element should not exceed 2 in. The detecting element is placed in close thermal proximity to the part where the local temperature is to be measured. Examples of local temperature detectors are:

- (1) Thermocouple
- (2) Small resistance thermometer
- (3) Thermistor

These are frequently installed as permanent parts of a machine in places not accessible to mercury or alcohol thermometers. They are used to determine the local temperature of winding conductors, core laminations within a package, and winding temperature between coil sides. Since the temperatures measured by local temperature detectors may deviate substantially from those determined by the thermometer method, the embedded-detector method, and the resistance method, the temperatures so measured should not be

interpreted in relation to standards written in terms of these other methods.

6.4 Temperature Readings

6.4.1 General. The following subsections describe three methods of temperature measurement. These are used to measure the temperature of the windings, the stator core, the incoming cold coolant, and the exhaust hot coolant. Each method of measurement is best suited for particular parts of a machine. Thus in a given test, it may be desirable to use all three methods to measure the temperature in the various parts of the machine.

6.4.2 Thermometer Method. Temperatures taken by the thermometer method (see 6.3.1.1) may be measured on the following parts during the temperature tests and, if specified, after shutdown.

- (1) Stator coils — at least two places
- (2) Stator core — at least two places
- (3) Ambient
- (4) Air discharged from frame, or air discharge ducts; or internal coolant discharged to the inlet of coolers of machines with recirculating cooling system
- (5) Frame
- (6) Bearings (when part of the machine)
- (7) The temperature sensing elements should be located to obtain the highest temperatures, except for ingoing and discharge air or other coolant temperature, for which they should be placed to obtain average values

6.4.3 Embedded-Detector Method. Temperatures of the winding of machines equipped with embedded detectors should be determined by the embedded-detector method (see 6.3.1.2) during the temperature test. Temperature measurements of all embedded detectors should be recorded and the maximum of these values reported as the temperature of the winding by embedded detector. Readings after shutdown are not normally required.

6.4.4 Resistance Method for Windings. Temperatures of the stator (and rotor of wound-rotor machine) winding may be determined by the resistance method (see 6.3.1.3) after shutdown. The resistance should be measured across any two-line terminals for which a reference value of resistance has been measured at a known temperature. The resistance should be measured directly at the machine terminals.

6.5 Measurement of Ambient Temperature.

For the procedure to be followed in the measurement of ambient temperature, see IEEE Std 119-1974 [10].

6.6 Procedure. The machine may be loaded by one of the methods outlined in 6.2.3. The loading may be determined by direct measurement of output or input. A machine having more than one rating shall be tested at the rating which produces the greatest temperature rise. In cases where this cannot be predetermined, the machine shall be separately tested at each rating.

6.6.1 The test shall be continued for the specified time (for machines not continuously rated), or until constant temperatures have been reached. Unless otherwise specified, a short-time test shall commence only when machine parts are within 5 °C of the ambient temperature.

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

6.6.3 For continuously rated machines, readings shall be taken at intervals of $\frac{1}{2}$ h or less. For noncontinuously rated machines, readings shall be taken at intervals consistent with the time rating. The temperature test shall continue until there is 1 °C or less change in temperature rise between two successive readings.

6.6.4 The measurement of temperatures after shutdown by the resistance method requires a quick shutdown of the machine at the end of the temperature test. A carefully planned procedure and an adequate number of people are required to obtain readings soon enough to give reliable data.

If the initial resistance reading is obtained within the time interval indicated in the following table, this reading is accepted as the temperature measurement and extrapolation to the instant of switching off the power is unnecessary.

Rating	Time Delay After Switching Off Power (Seconds)
50 kVA or hp, and less	30
50 kVA or hp, to 200 kVA or hp	90
Above 200 kVA or hp	120

If the initial resistance reading cannot be made within the time delay given by the table, it shall be made as soon as possible and additional resistance readings shall be taken at intervals of approximately 60 s until resistance readings have begun a decided decline from their maximum values. A curve of these readings shall be plotted as a function of time and extrapolated to the time delay given by the above table for the rating of the machine. A semilogarithmic plot is recommended, where resistance (or temperature) is plotted on the logarithmic scale. The value of resistance (or temperature) thus obtained shall be considered as the resistance (or temperature) at shutdown. If successive measurements show increasing temperatures after shutdown, the highest value shall be taken. Where the first reading cannot be taken within twice the time delay given by the table, the time shall be subject to agreement.

6.6.5 Resistance measurements required for determination of temperatures shall be taken and recorded until the readings decrease. 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 [9].

6.7 **Temperature Rise.** When the machine is ventilated by the immediately surrounding air, the temperature rise is the observed machine temperature minus the ambient temperature. When the machine is ventilated by air obtained from a remote source or a heat exchanger, the temperature rise is the observed machine temperature minus the ingoing air temperature entering the machine.

Machines may be tested at any altitude not exceeding 3300 ft (1000 m) and with cooling-air temperatures between 10 °C and 40 °C without correction of temperature rise.

NOTE: At higher altitudes, the temperature rise will be greater than at sea level. While an exact conversion is not available, a commonly used method allows for the influence of altitude. For each 330 ft (100 m) above 3300 ft, the temperature rise is reduced by 1% to obtain the rise expected at sea level.

7. Miscellaneous Tests

7.1 **Insulation Resistance.** Insulation-resistance tests are not generally made on new machines

unless specifically requested. For maintenance purposes, insulation-resistance tests are of value. All accessories, such as surge capacitors, surge arresters, current transformers, etc, which have leads located at the machine terminals, shall be disconnected during this test.

7.1.1 For test methods see ANSI/IEEE Std 43-1974 (R1979) [3].

7.2 High-Potential Test

7.2.1 For measurement of high-potential test voltage, see ANSI/IEEE Std 4-1978 [2]. The voltmeter method of measurement is commonly used.

7.2.2 The high-potential test voltage shall be successively applied between each electric circuit and the frame, with the windings not under test and the other metal parts connected to the frame. Interconnected polyphase windings are considered as one circuit. All accessories, such as surge arresters, current transformers, etc, which have leads located at the machine terminals, shall be disconnected during this test.

7.2.2.1 No leads shall be left unconnected during the test as this may cause an extremely severe strain at some point of the winding. In making the test, the voltage shall be increased to full value as rapidly as possible while still maintaining an accurate meter reading, and the full voltage should be maintained for 1 min. It should then be reduced at a rate that will bring it to one-quarter value or less in not more than 15 s.

WARNING: *Due to the high voltage used, high-potential tests should be conducted only by experienced personnel, and adequate safety precautions should be taken to avoid injury to personnel and damage to property. For the procedures recommended, refer to ANSI/IEEE Std 4-1978 [2] and IEEE Std 62-1978 [7].*

7.3 **Winding Resistance Measurements.** For the procedures recommended in the measurement of resistance, refer to IEEE Std 118-1978 [9], IEEE Std 119-1974 [10], or 6.3.1 of this standard.

7.4 **Shaft Current and Bearing Insulation.** Irregularities in the magnetic circuit may cause a small amount of flux to link the shaft, with the result that an electromotive force is generated between the shaft ends. This electromotive force may cause a current to flow

through the shaft, bearings, bearing supports, and machine framework, and back to the other end of the shaft, unless this circuit is interrupted by insulation. (While other causes may produce a shaft voltage, not involving a difference in potential from one end of the shaft to the other, no special tests are described for the resulting effects because each of these sources would require specially adapted methods of test, essentially of a research nature.)

For Methods 1 through 3, the machine should be run at rated speed and rated voltage, unless other operating conditions are specified.

7.4.1 Method 1. Across Bearing Oil Film, Uninsulated Bearings. This method requires that the insulating properties of the bearing oil film be adequate to withstand the shaft voltage without breaking down. The presence of shaft voltage or current may be determined by running the machine at rated speed and voltage, and connecting a low-resistance conductor from the shaft to the frame of the machine at one bearing, and a low-range alternating-current voltmeter (or a high-range alternating-current ammeter) with low-resistance leads from the shaft to the frame at another bearing. Deflection of the meter indicates the presence of a voltage that may produce shaft currents. If the meter does not deflect, there is either insufficient voltage present or the bearing oil film is not acting as an adequate insulator.

Another method to determine the presence of shaft voltage which may cause damaging current to flow in the bearings is to measure the voltage from end to end of the shaft, with a high-resistance voltmeter such as a vacuum-tube voltmeter, while the machine is running at rated speed and voltage.

7.4.2 Method 2. Across Bearing Insulation. Many machines have one or more bearings insulated to eliminate shaft currents. In the following subsections, it is assumed that insulation is located between the bearing and the frame of the machine. To determine the presence of a voltage that would produce shaft currents in such a machine, a low-resistance conductor is connected from the shaft to the uninsulated bearing, to short-circuit the oil film, and a low-range alternating-current voltmeter (or a high-range alternating-current ammeter) is connected between the shaft and the frame successively at each insulated bearing. Deflection of the meter indicates the presence of a voltage that would produce shaft

currents if the bearing insulation were not present.

7.4.3 Method 3. Bearing Insulation. The insulation can be tested by connecting a low-range alternating-current voltmeter (or a high-range alternating-current ammeter) across the insulation. A low-resistance conductor may be applied from the shaft to each bearing, to short-circuit the oil film. Deflection of the meter, in this case, is evidence that the insulation is at least partially effective. If there is no deflection of the meter, either the insulation is defective or there is no shaft voltage present.

7.4.4 Method 4. Bearing Insulation. A layer of heavy paper is placed around the shaft to insulate the journals of the uninsulated bearings. The coupling of the driving or driven units should be disengaged, if it is not insulated. Then from a 110 V-125 V source, with either a filament lamp suitable for the circuit voltage or a voltmeter of approximately 150 V full scale with a resistance in the range of 100-300 Ω/V placed in a series with the voltage source, two leads should be run, one to the insulated bearing and the other to the frame (across the insulation). If the lamp filament does not show color (or if the reading of the voltmeter does not exceed 60 V) the insulation may be considered satisfactory.

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

7.4.5 Method 5. Double Insulation. On some machines, bearings are provided with two layers of insulation with a metallic separator between them. The test of Method 4 is applied between the metallic separator and the frame of the machine. This test should be carried out on each of the various multiple paths between the shaft and the frame where insulated bearings are used (for example, thermometer tubes, control pipes for a hydraulic turbine, hydrogen seals, and insulated couplings). This test may be made with the machine stationary or running. The test should be supplemented by careful visual inspection to assure that there are no possible parallel paths which are not provided with insulation.

7.5 Noise. See IEEE Std 85-1973 (R1980) [8].

Table 1

Speed (r/min)	Minimum Compression (in — mm)	
900	$\frac{1}{4}$	25.4
1800	$\frac{1}{16}$	6.35
3600	$\frac{1}{64}$	1.6
7200	$\frac{1}{64}$	0.4

7.6 Vibration. Both horizontal and vertical vibration measurements shall be made at the machine bearing housings. The double amplitude on either end in either direction is taken as the measure of the vibration. Mounting conditions will affect the vibration of a machine. To obtain measurements as nearly as possible independent of mounting conditions, the

machine shall be placed on flexible pads or springs. The compression of the flexible pads or springs (downward) by the weight of the machine alone shall not be less than the values shown in Table 1.

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

When the machine, because of its size or for some other reason, cannot be mounted on flexible pads or springs, the machine shall be mounted on a foundation whose natural frequency is removed by at least 25% from the rotational exciting frequency.

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

8. Forms

FORM A-1
Typical Report of Test Form for Routine Tests on Induction Motors

Name of Manufacturer _____
 Address of Manufacturer _____
 Purchaser _____
 Date of Test _____
 Manufacturer's Order No. _____
 Purchaser's Order No. _____

Nameplate Data

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

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

Test Characteristics

Serial No	No Load					Locked Rotor					Wound Rotor Open-Circuit Voltage	High Potential Test Voltage	Stator Winding Resistance Between Terminals	
	Volts	Frequency Hz	Speed r/min	Amperes	Kilo-watts*	Volts	Frequency Hz	Amperes	Kilo-watts*	Ohms			Temperature °C	

*If measured, optional.

Notes:

Data on test from _____ motor.
(this or duplicate)

Approved by _____ Date _____
(Engineer)

FORM A-2
Typical Report of Test Form for Induction Motors

Name of Manufacturer _____ Manufacturer's
 Address of Manufacturer _____ Order No. _____
 Serial No. _____ Date of Test _____
 Model No. _____ Purchaser's
 Purchaser _____ Order No. _____

Nameplate Rating

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

Temperature Rise

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

Characteristics

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

Torque and Starting Current

Break-Down Torque in _____**	Locked-Rotor Torque in _____** with _____ % volts applied	Starting Current Amperes (locked rotor) with _____ % volts applied

High Potential Tests

Volts ac for _____ Sec	
Stator	Rotor

Efficiencies and Power Factor

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

Notes:

Data from test on _____ motor.
(this or duplicate)

*Indicate method as:
 Thermometer
 Thermocouple
 Resistance
 Embedded Detector.

Approved by _____ Date _____

**Indicate torque units as N·m or lb-ft.

Form B
Method B: Input-Output Test of Induction Machine

Type _____ Design _____ Frame _____ Hp _____ Phase _____
 Frequency _____ Volts _____ Synchronous r/min _____ Serial No _____
 Degrees C Temperature Rise _____ Time Rating _____ Model No _____

Test Point	1	2	3	4	5	6
(t_t) Stator-Winding Temperature, °C						
Ambient Temperature, °C						
Frequency, Hz						
Observed Slip, r/min						
*Corrected Slip, r/min						
Speed, r/min						
Torque, _____ **						
(1) Dynamometer Correction _____ **						
(2) Corrected Torque _____ **						
(3) Power Output, hp						
Line Current, amperes						
Power Factor, percent						
Observed Power Input, watts						
(a) Stator I^2R Loss, watts, at (t_s) °C						
(b) Stator I^2R Loss, watts, at t_t						
(4) Input Correction = (a) - (b)						
(5) Corrected Power Input, watts						
(6) Efficiency, percent						

Performance Curve _____

*See 5.4.1.

**Indicate torque units as N·m, or lb·ft.

Data Obtained from Performance Curve

Load, percent of rated	25	50	75	100	125	150
Power Factor, percent						
Efficiency, percent						
Speed, r/min						
Line Current, amperes						

t_t = temperature of stator winding as determined from stator resistance or by temperature detector during test
 t_s = specified temperature for resistance correction (see 5.3.1)

(1) "Corrects" for windage and bearing loss torque of dynamometer and is equal to

$$\frac{(A - B)}{kn} - C$$

where:

A = power, in watts, required to drive machine when coupled to dynamometer with dynamometer armature circuit open

B = power, in watts, required to drive machine when running free and uncoupled.

C = torque output registered by dynamometer during test "A"

k = 0.1047 for torque in N·m

k = 0.1420 for torque in lb·ft

n = rotational speed in r/min.

(2) Corrected torque is equal to observed torque plus correction (1).

(5) This value is equal to observed power in watts plus correction (4).

(6) Percent efficiency = $\frac{(3)}{(5)} \cdot 74.570$

Form E
Method C: Duplicate Machine Performance of Induction Machine
Method E: Segreated Losses Performance of Induction Machine

Type _____ Design _____ Frame _____ Hp _____ Phase _____
 Frequency _____ Volts _____ Synchronous r/min _____ Serial No _____
 Degrees C Temperature Rise _____ Time Rating _____ Model No _____

Test Point	1	2	3	4	5	6
Stator-Winding Temperature, t_t °C						
Ambient Temperature, °C						
Frequency, Hz						
Observed slip, r/min						
(1) Corrected slip, r/min						
(2) Speed, r/min						
Line Current, amperes						
Power Factor, percent						
(3) Observed Power Input, watts						
Stator I^2R Loss at t_s , watts						
Core Loss, watts						
(4) Power Input to Rotor, watts						
(5) Rotor I^2R Loss, watts						
Friction and Windage Loss, watts						
Stray-Load Loss, watts						
(6) Total Losses, watts						
(7) Power Output, watts						
Power Output, hp						
(8) Efficiency, percent						

Performance Curve _____

Summary of Characteristics

Load, percent of rated	0	25	50	75	100	125
Power Factor, percent						
Efficiency, percent						
Speed, r/min						
Line Current, amperes						

t_t = temperature of stator winding as determined from stator resistance or by temperature detector during test
 t_s = specified temperature for resistance correction (see 5.3.1).

(1) See 5.4.1.

(2) Calculated as synchronous speed minus corrected slip speed, r/min.

(4) Is equal to observed watts input, minus stator I^2R loss, minus core loss.

(5) Is equal to product of rotor input and corrected slip expressed as a fraction of synchronous speed.

(6) Is equal to sum of stator and rotor I^2R losses, friction and windage and core loss, and stray-load loss.

(7) Is equal to watts input minus total losses.

(8) Percent efficiency = $100 - \left[\frac{(6)}{(3)} \cdot 100 \right]$

Form F-1

Method F: Equivalent Circuit Nomenclature and Equations for Determining Machine Constants

NOTE: Unless otherwise noted, all impedances, admittances, and voltages are per phase for two-phase motors and per phase wye for three-phase motors. Powers and volt-amperes are per complete motor.

Nomenclature

V = phase voltage, volts
 f = frequency, hertz
 I_1 = line or stator current, amperes
 I_2 = rotor current, amperes
 s = slip in per unit of synchronous speed
 m = number of phases
 r_1 = stator resistance corrected to specified temperature t_s , ohms
 r_1' = stator resistance at temperature during no load test, ohms
 r_1'' = stator resistance at temperature during impedance test, ohms
 r_2 = rotor resistance referred to stator at specified temperature t_s , ohms
 r_2'' = rotor resistance referred to stator at temperature during impedance test, ohms
 x_1 = stator leakage reactance, ohms
 x_2 = rotor leakage reactance referred to stator, ohms
 x_M = magnetizing reactance, ohms
 b_M = magnetizing susceptance, ohms⁻¹
 r_{fe} = core resistance, ohms
 g_{fe} = core conductance, ohms⁻¹
 VAR = reactance volt-ampere, vars
 W = power, watts
 W_h = core loss, watts
 W_f = friction and windage loss, watts
 W_{LL} = stray-load loss, watts
 $= LL_s + LL_r$

Subscripts:

L = quantities pertaining to impedance test
 o = quantities pertaining to no-load test or operation

NOTES: (1) For three-phase motors, the per phase wye stator resistance is one-half of the terminal to terminal resistance.

(2) Design A, B, C, and D motors are defined in ANSI/NEMA MG1-1972 [5].

Procedure

A relationship between x_1 and x_2 must be assumed. When design details are available, use the calculated ratio $\left(\frac{x_1}{x_2}\right)$

otherwise use:

$\left(\frac{x_1}{x_2}\right) = 1.0$ for Design A motors, Design D motors, and wound-rotor motors

$\left(\frac{x_1}{x_2}\right) = 0.67$ for Design B motors

$\left(\frac{x_1}{x_2}\right) = 0.43$ for Design C motors

$$VAR = \sqrt{(mVI_1)^2 - W^2}$$

$$x_M = \frac{mV_0^2}{VAR_0 - mI_1^2 x_1} \left(\frac{1}{1 + \frac{x_1}{x_M}} \right)^2 \quad (1)$$

$$x_{1L} = \frac{VAR_L}{mI_{1L}^2 \left(1 + \frac{x_1}{x_2} + \frac{x_1}{x_M} \right)} \left(\frac{x_1}{x_2} + \frac{x_1}{x_M} \right) \quad (2)$$

$$x_1 = \frac{f}{f_L} x_{1L} \quad (3)$$

Equations (1), (2), and (3) may be solved as follows:

- 1) Solve Eq (1) for x_M , assuming a value of $\frac{x_1}{x_M}$ and x_1 .
- 2) Solve Eq (2) for x_{1L} , using the value of $\frac{x_1}{x_M}$ from Step 1.
- 3) Solve Eq (3) for x_1 .
- 4) Solve Eq (1) for x_M , using x_1 from Step 3 and a ratio of $\frac{x_1}{x_M}$ from Steps 1 and 3.
- 5) Continue iteration solution until stable values of x_1 and x_M are obtained within 0.1%.

$$b_M = \frac{1}{x_M} \quad (4)$$

$$x_2 = \frac{x_1}{\left(\frac{x_1}{x_2}\right)} \quad (5)$$

$$W_h = W_o - W_f - mI_1^2 r_1' \quad (6)$$

Determine W_f per 5.6.2

$$g_{fe} = \frac{W_h}{mV_0^2} \left(1 + \frac{x_1}{x_M} \right)^2 \quad (7)$$

$$r_{fe} = \frac{1}{g_{fe}} \quad (8)$$

$$r_2'' = \left(\frac{W_L}{mI_{1L}^2} - r_1'' \right) \left(1 + \frac{x_2}{x_M} \right)^2 - \left(\frac{x_2}{x_1} \right)^2 (x_{1L}^2 g_{fe}) \quad (9)$$

Form F-3
Method F: Solution of Equivalent Circuit

Motor Serial No. _____ Model No. _____
Type _____ Horsepower _____ Voltage _____ Synchronous Speed _____ Frequency _____ m =Phases _____

Before starting calculations, fill in following items, obtained from previous tests.

r_2 = _____ V = phase volts _____ I_t _____ and W_{LL} _____ from Form F-2
also all the items below which are marked with an asterisk.

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

Item	Description	1	2	3	4	5	6	7	8
1	s =slip, per unit								
2	r_2/s								
* 3	x_2								
4	$Z_2^2 = (2)^2 + (3)^2$								
5	$g_2 = (2)/(4)$								
* 6	g_{fe}								
7	$g = (5) + (6)$								
8	$-b_2 = (3)/(4)$								
* 9	$-b_M =$								
10	$-b = (8) + (9)$								
11	$Y^2 = (7)^2 + (10)^2$								
12	$r_g = (7)/(11)$								
*13	r_1 = resistance per phase								
14	$r = (12) + (13)$								
15	$x_g = (10)/(11)$								
*16	$x_1 =$								
17	$x = (15) + (16)$								
18	$Z = \sqrt{(14)^2 + (17)^2}$								
19	$I_1 = V/(18)$								
20	$I_2 = I_1 / \sqrt{(4) \cdot (11)}$								
21	watts Input = $m \cdot (19)^2 \cdot (14)$								
22	Sec. Input = $m \cdot (20)^2 \cdot (2)$								
23	Stator $I^2R = m \cdot (19)^2 \cdot (13)$								
24	Core Loss = $m \cdot (19)^2 \cdot (6)/(11)$								
25	Sec. $I^2R = (1) \cdot (22)$								
26	Friction and Windage Loss								
27	$W_{LL} = W_{LL} \cdot [(20)/I_t]^2$								
28	Losses=Items (23) through (27)								
29	watts Output = (21) - (28)								
30	Eff. (%)=100 $\cdot [1 - (28)/(21)]$								
31	PF (%)=100 $\cdot (14)/(18)$								
32	hp Output = (29)/746								
33	Speed= [1 - (1)] \cdot Sync. speed								
34	Torque= $K_T \cdot (29)/(33)$								

For torque in	K_T =
lbf-ft	7.043
ozf-ft	112.69
newton-meters	9.549