$$\text{efficiency} = \frac{\text{input power} - \text{losses}}{\text{input power}} \tag{74}$$

A form commonly used for generators is

$$\text{efficiency} = \frac{\text{output power}}{\text{output power} + \text{losses}} \tag{75}$$

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

6.2 Efficiency test methods

6.2.1 Overview

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

a)	Method A	Input-output
b)	Method B	Input-output with segregation of losses and indirect measurement of stray-load loss
c)	Method B1	Input-output with segregation of losses, indirect measurement of stray-load loss and an assumed temperature
d)	Method C	Duplicate machines with segregation of losses and indirect measurement of stray-load loss
e)	Method E	Electric power measurement under load with segregation of losses and direct measurement of stray-load loss
f)	Method E1	Electric power measurement under load with segregation of losses and assumed value of stray-load loss
g)	Method F	Equivalent circuit with direct measurement of stray-load loss
h)	Method F1	Equivalent circuit with assumed value of stray-load loss
i)	Method C/F	Equivalent circuit calibrated per Method C load point with indirect measurement of stray-load loss
j)	Method E/F	Equivalent circuit calibrated per Method E load point with direct measurement of stray-load loss
k)	Method E1/F1	Equivalent circuit calibrated per Method E load point with assumed value of stray-load loss

6.2.2 Guide for choice of efficiency test method

The input-output method (Efficiency Test Method A) should be limited to machines with ratings less than 0.7457 kW.

Horizontal machines rated at 0.7457 kW to 300 kW should be tested using Efficiency Test Method B, the input-output method with loss segregation.

Vertical machines in the range of 0.7457 kW to 300 kW should be tested by Efficiency Test Method B if the machine bearing construction permits. If the bearing construction does not permit Method B testing, Method E, E1, F, or F1 may be used.

Machines rated higher than 300 kW should be tested by Efficiency Test Method B, B1, C, E, E1, F, or F1 depending on the capability of the test facility. When proper test facilities are available, Method B should be selected when the precision and repeatability of this method is required.

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

6.3 Efficiency Test Method A—Input-output

6.3.1 Overview

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

6.3.2 Test procedure

6.3.2.1 Cold resistance

With the machine at ambient temperature, measure and record the winding(s) resistances and the ambient temperature. See 5.5.

6.3.2.2 Rated load temperature test

Perform a rated load temperature test in accordance with 5.9.3.2.

6.3.2.3 Test under load

Perform a load test in accordance with 5.7. The machine is loaded by means of a mechanical brake or dynamometer, see 5.7.2.

6.3.2.4 Calculations

Performance is calculated as shown in Form A in 9.2 with details of the calculations shown in Form A2 in 9.3. Dynamometer correction should be made, if applicable, as shown in 5.7.2.3. The stator I^2R loss and the slip are to be corrected for temperature as indicated.

6.3.2.5 Temperature correction

The stator power is corrected to the specified temperature. The amount of power correction required is determined by Equation (76).

$$P_c = I_t^2 R_s - I_t^2 R_t \tag{76}$$

where

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

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

The measured slip is corrected to the specified temperature using Equation (9) in 5.4.3.

6.3.3 Efficiency

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

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

6.4.1 Introduction

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

6.4.2 Test procedure

6.4.2.1 Introduction

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

6.4.2.2 Cold resistance

With the machine at ambient temperature, measure and record the winding(s) resistances and the ambient temperature. See 5.5.

6.4.2.3 Rated load temperature test

A rated load temperature test, using a dynamometer, is to be performed in accordance with 5.9.3.2. This test is not required when a rated load temperature test had previously been performed on a duplicate machine. Determine the specified temperature for the machine. See item a) or b) in 3.3.2.

6.4.2.4 Test under load

Perform a load test in accordance with 5.7. During this test, the machine shall be loaded by a dynamometer, see 5.7.2. The temperature of the stator winding shall be within 10 °C of the hottest temperature reading recorded during the rated load temperature test on this or the duplicate machine prior to the start of recording data for this test. Perform the test as quickly as possible to minimize temperature changes in the machine during testing. When necessary, a dynamometer correction test shall be made. See 5.7.2.3.

6.4.2.5 No-load test

Perform a no-load test in accordance with 5.6, including the bearing loss stabilization step of 5.6.2.

6.4.3 Calculations

6.4.3.1 Calculation form

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

6.4.3.2 Friction and windage loss

See 5.6.5.

6.4.3.3 Core loss

The relationship between core loss and terminal voltage at no load shall be determined following the procedure in 5.6.6.

The core loss for each of the load points shall be determined based on the value of stator core voltage found by subtracting the resistive voltage drop in the stator winding from the average measured terminal voltage. This voltage is synonymous with the rotor voltage across the core loss resistance in Figure 6 when the voltage drop across the stator leakage reactance is considered to be negligible.

The stator core voltage, V_{core}, shall be calculated using Equation (77).

$$V_{core} = \sqrt{\left[V_t - \frac{\sqrt{3}}{2} \times I_t \times R_t \times PF\right]^2 + \left[\frac{\sqrt{3}}{2} \times I_t \times R_t \times \sqrt{1 - PF^2}\right]^2} \tag{77}$$

where

V_{core} is the stator core voltage
V_t is the average stator line-to-line voltage, in volts, during the load test
I_t is the line current, in amperes, during the load test
R_t is the average stator winding resistance, in ohms, during the load test as determined in 6.4.3.4
PF is the machine power factor during the load test as determined using Equation (70) in 5.12.1

Using the no-load test data from between 60% and 125% of rated voltage, either plot a curve of the no load core loss against voltage or determine an empirical relationship of core loss as a function of voltage using an appropriate curve fit. The core loss at the calculated value of the stator core voltage for each of the load test points shall be determined from the plot or the empirical relationship.

6.4.3.4 Stator I^2R loss

See 5.3.

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

From the rated load temperature test of 6.4.2.3, obtain the winding resistance at shutdown and the temperature at shutdown by both the winding resistance and by local detector. This should be the same local detector being used during the load test. A value closely approximating the average temperature can then be determined by Equation (78).

$$t_A = \frac{t_{TR} t_t}{t_{TTD}} \tag{78}$$

where

t_A is the developed average temperature, in degrees Celsius, for use in the loss calculations
t_{TR} is the total temperature, in degrees Celsius, from the shut down of the temperature test
t_t is the temperature, in degrees Celsius, by detector during the load test
t_{TTD} is the temperature, in degrees Celsius, by detector from the shutdown of the temperature test

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

6.4.3.5 Rotor I^2R loss

See 5.4. The first calculation of rotor I^2R loss is based on actual speed or slip measurement for each point and no adjustments are required.

6.4.3.6 Apparent total loss

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

6.4.3.7 Stray-load loss determination (indirect method)

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

6.4.3.8 Smoothing of the stray-load loss

Smooth the stray-load loss data by using a linear regression analysis based on expressing the stray-load loss as a function of the square of the load torque. The results of the analysis should be as shown in Equation (79).

$$P_{SL} = AT^2 + B \tag{79}$$

where

P_{PL} is the stray-load loss, in watts, as plotted versus torque squared
T is the torque, in Netwon·meters
A is the slope
B is the intercept with the zero torque line

If this analysis shows the slope is negative, or if the correlation factor is less than 0.9, delete the worst point and repeat the regression analysis. If this increases the correlation factor to 0.9 or larger, use the second regression; if not, or if the slope is still negative, the test is unsatisfactory. Errors in the instrumentation or test readings, or both, are indicated. The source of the error should be investigated and corrected, and the test under load, see 6.4.2.4, should be repeated.

6.4.4 Corrections

6.4.4.1 Corrected stray-load loss

The stray-load loss curve of 6.4.3.8 is corrected by shifting the curve to go through the origin while maintaining the original slope. The result of this correction is Equation (80), which is used to determine the corrected value of stray-load loss, P_{SLc}, for each load point.

$$P_{SLc} = AT^2 \tag{80}$$

where

A is the slope of the of the P_{SL} versus T^2 curve defined in 6.4.3.8
T is the torque, in Netwon·meters, for each load point as used in 6.4.3.8

6.4.4.2 Temperature correction of stator I^2R loss

A corrected stator I^2R loss for each of the load points is calculated using the average stator resistance corrected to the specified temperature. Using the resistance and the total temperature by resistance at shutdown from 6.4.2.3 as the reference values, correct that resistance to the specified temperature using Equation (3). Calculate the loss as in 5.3.

6.4.4.3 Temperature correction of rotor I^2R loss

A corrected rotor I^2R loss for each of the load points is calculated as in 5.4, Equation (4) or Equation (5), using the value of slip for each of the points corrected to the specified temperature, using Equation (9), and using the corrected value of the stator I^2R loss, from 6.4.4.2, for each load point. The slip used in Equation (4) or Equation (5) is the slip used in 6.4.3.5 corrected to the specified temperature from the developed average temperature from 6.4.3.4.

6.4.4.4 Corrected total loss

A corrected total loss for each of the load points is determined as the sum of the friction and windage loss (see 6.4.3.2), the core loss (see 6.4.3.3), the corrected stray-load loss (see 6.4.4.1), the corrected stator I^2R loss (see 6.4.4.2), and the corrected rotor I^2R loss (see 6.4.4.3).

6.4.4.5 Corrected mechanical power

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

6.4.5 Efficiency

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

6.4.6 Power factor

The power factor of the machine shall be determined for each load point using Equation (70). See 5.12.1.

6.4.7 Summary of characteristics

The summary of characteristics is a listing of the power factor, the efficiency, the speed, and the line current at precise load points. To obtain this information, plot the values from the analysis for the line current, speed, and efficiency versus the output power. Fit curves to these data and pick off the values for the desired load points. The power factor is computed for each precise load point from its amperes, volts, and input watts as in Equation (70).

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

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

6.5.1 Introduction

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

6.5.2 Test procedure

6.5.2.1 Introduction

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

6.5.2.2 Cold resistance

With the machine at ambient temperature, measure and record the winding(s) resistances and the ambient temperature. See 5.5.

6.5.2.3 Temperature

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

6.5.2.4 No-load test

Perform a no-load test in accordance with 5.6 including the bearing loss stabilization step of 5.6.2.

6.5.2.5 Test under load

For this test, the machine shall be loaded by a dynamometer, see 5.7.2. The temperature of the stator winding shall be within 10 °C of the specified temperature, as selected in 6.5.2.3, prior to the start of recording data for this test. Perform the test as quickly as possible to minimize temperature changes in the machine during testing. When necessary, a dynamometer correction test shall be made. See 5.7.2.3.

6.5.3 Calculations

6.5.3.1 Calculation form

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

6.5.3.2 Friction and windage loss

See 5.6.5.

6.5.3.3 Core loss

See 6.4.3.3.

6.5.3.4 Stator I^2R loss

See 5.3. Calculate loss with winding resistance corrected to the test temperature.

6.5.3.5 Rotor I^2R loss

See 5.4. This first calculation of rotor I^2R loss is based on actual speed or slip measurement for each point and no adjustments are required.

6.5.3.6 Apparent total loss

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

6.5.3.7 Stray-load loss determination (indirect method)

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

6.5.3.8 Smoothing of the stray-load loss

Smooth the stray-load loss data by using a linear regression analysis based on expressing the stray-load loss as a function of the square of the load torque. The results of the analysis should be as shown in Equation (79).

If this analysis shows the slope is negative, or if the correlation factor is less than 0.9, delete the worst point and repeat the regression analysis. If this increases the correlation factor to 0.9 or larger, use the second regression; if not, or if the slope is still negative, the test is unsatisfactory. Errors in the instrumentation or test readings, or both, are indicated. The source of the error should be investigated and corrected, and the test under load, see 6.5.2.5, should be repeated.

6.5.4 Corrections

6.5.4.1 Corrected stray-load loss

The corrected value of stray-load loss, P_{SLc} is determined using Equation (80) with T equal to the torque for each of the load points and A is the slope of the function curve as determined in 6.5.3.8.

6.5.4.2 Temperature correction of stator I^2R loss

A corrected stator I^2R loss for each of the load points is calculated using the average cold stator resistance from 6.5.2.2 corrected to the specified temperature. Calculate the loss as in 5.3.

6.5.4.3 Temperature correction of rotor I^2R loss

A corrected rotor I^2R loss for each of the load points is calculated as in 5.4, Equation (4) or Equation (5), using the value of slip for each of the points corrected to the specified temperature, using Equation (9), and using the corrected value of the stator I^2R loss, from 6.5.4.2, for each load point. The slip used in Equation (4) or Equation (5) is the slip used in 6.5.3.5 corrected to the specified temperature from the test temperature at the applicable test point.

6.5.4.4 Corrected total loss

A corrected total loss for each of the load points is determined as the sum of the friction and windage loss (see 6.5.3.2), the core loss (see 6.5.3.3), the corrected stray-load loss (see 6.5.4.1), the corrected stator I^2R loss (see 6.5.4.2), and the corrected rotor I^2R loss (see 6.5.4.3).

6.5.4.5 Corrected mechanical power

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

6.5.5 Efficiency

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

6.5.6 Power factor

The power factor of the machine shall be determined for each load point using Equation (70) of 5.12.1.

6.5.7 Summary of characteristics

The summary of characteristics is a listing of the power factor, the efficiency, the speed, and the line current at precise load points. To obtain this information, plot the values from the analysis for the line current, speed, and efficiency versus the output power. Fit curves to these data and pick off the values for