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Energy Efficiency Test Methods for Three-Phase Induction Motors

Performance of Electrical Products

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Preface

This is the second edition of CSA Standard C390, *Energy Efficiency Test Methods for Three-Phase Induction Motors*. It supersedes the previous edition published in 1985 and Preliminary Standards C390.1 and C390.2, published in 1982.

The purpose of this Standard is to specify test methods for three-phase induction motors to determine energy efficiency in support of an informative program. This Standard is written using metric units of measurement in accordance with the International System of Units (SI).

This edition includes revisions to the following:

(a) definition and determination requirements for nominal efficiency;
(b) marking; and
(c) minimum energy performance requirements.

Because of the need to conserve vital national energy resources, in addition to knowing a motor energy efficiency, it is important that motor users and specifiers understand the selection, application, and maintenance of electric motors in order to improve the management of electrical energy consumption. Energy management, as related to electric motors, is the consideration of the factors that contribute to reducing the energy consumption of a total electric motor drive system. Among the factors to be considered are the motor design and application.

An electric motor is an energy converter, converting electrical energy to mechanical energy. For this reason an electric motor should be considered as always being connected to a driven machine or apparatus with specific operating characteristics that dictate the starting, running load, and speed-torque characteristics of the motor. Consequently, the selection of the motor most suitable for a particular application is based on many factors, including the requirements of the driven equipment (eg, starting and acceleration, speed, load, duty cycle), service conditions, motor efficiency, motor power factor, and initial cost. These application factors often conflict with one another.

The system efficiency is determined by the quality of the power supply, voltage balance, wave shape, and the supply cables as well as the product of the efficiencies of all the components in the drive system. In addition to the motor these components include the driven equipment (such as fans, pumps and compressors) and power transmission components (such as belts, pulleys, and gears). Other components that are not part of the driven system will affect the overall system efficiency; some of these are refrigerator and air conditioning evaporator and condenser coils, piping associated with pumps, and ducts and baffles associated with fans and blowers.

Good energy management is the successful application of the motor and its driven components that results in the least energy consumption.

Mandatory requirements in the main text are supplemented by Appendices A, B, and C to help the user implement it. This Preface and Appendices A, B, and C are for information only and do not contain any mandatory requirements.

This Standard was prepared by the CSA Technical Committee on Performance of Electric Motors under the jurisdiction of the CSA Standards Steering Committee on Performance of Electrical Products, and was formally approved by these Committees.

July 1993

Notes:

(1) *Use of the singular does not exclude the plural (and vice versa) when the sense allows.*

(2) *Although the intended primary application of this Standard is stated in its Scope, it is important to note that it remains the responsibility of the users of the Standard to judge its suitability for their particular purpose.*
(3) *CSA Standards are subject to periodic review, and suggestions for their improvement will be referred to the appropriate committee.*
(4) *All enquiries regarding this Standard, including requests for interpretation, should be addressed to Canadian Standards Association, Standards Development, 178 Rexdale Boulevard, Rexdale, Ontario M9W 1R3.*
Requests for interpretation should
(a) define the problem, making reference to the specific clause, and, where appropriate, include an illustrative sketch;
(b) provide an explanation of circumstances surrounding the actual field condition; and
(c) be phrased where possible to permit a specific "yes" or "no" answer.
Interpretations are published in CSA's periodical Info Update. *For subscription details, write to CSA Sales Promotion,* Info Update, *at the address given above.*

Foreword

The Canadian Standards Association provides certification services for manufacturers who, under license from CSA, wish to use the appropriate registered CSA Marks on certain products of their manufacture to indicate conformity with CSA Standards.

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C390-93
Energy Efficiency Test Methods for Three-Phase Induction Motors

1. Scope

1.1
This Standard specifies the test methods to be used in measuring the energy efficiency of three-phase induction motors in support of a consumer/user information program.
The method of determining and marking the nominal efficiency values are also specified.

1.2
This Standard applies to three-phase induction motors rated 0.746 kW at 1800 r/min (or equivalent*) and greater.
**An equivalent motor is a motor with the same torque output but with different kilowatt output and speed. Torque varies as kilowatts per revolutions per minute.*

1.3
The test methods detailed in this Standard for three-phase induction motors are segregated in relation to specific kilowatt ratings according to the following:

Motor	Test Methods
0.746 to 37.5 kW at 1800 r/min or equivalent*	(1)
Over 37.5 to 150 kW at 1800 r/min or equivalent*	(1) or (2)
Over 150 kW at 1800 r/min or equivalent*	(1), (2), or (3)

**An equivalent motor is a motor with the same torque output but with different kilowatt output and speed. Torque varies as kilowatts per revolutions per minute.*

1.4
This Standard does not apply to liquid-filled motors such as submersible motors.

2. Definitions

2.1
The following definitions apply in this Standard:

Core loss—the hysteresis and eddy current losses in the iron.

Dynamometer test—a test in which the mechanical power output of a machine acting as a motor is determined by the shaft torque, by means of a dynamometer, together with the rotational speed.

Efficiency—one of the following ratios determined in consistent units and expressed as a percentage:
(a) output/input;
(b) (input – losses)/input;
(c) output/(output + losses).

Input—the electrical power measured at the terminals of the motor.

Load—all numerical values of the electrical and mechanical quantities that signify the demand to be made on an induction motor.

No load—the state of a motor running while disconnected from any load.

Nominal efficiency—the average efficiency of a large population of motors of the same design (see Clause 9).

Output—the mechanical power measured at the shaft of a motor.

Rated value—the numerical value of a quantity included in the rating.

Rating—the whole of the numerical values of the electrical and mechanical quantities with their duration and sequence, assigned to the motor by the manufacturer and stated on the rating plate.

Rotor winding (I^2R) loss—the losses in the rotor winding (R being a variable with temperature).

Stator winding (I^2R) loss—the losses in the stator winding (R being a variable with temperature).

Stray-load losses—the additional fundamental and high-frequency losses in the iron; strand and circulating-current losses in the stator winding; and harmonic losses in the rotor conductors under load. These losses are assumed to be proportional to the rotor current squared.

Thermal equilibrium—occurs when the state of constant temperature is reached and the observed temperature rise of the motor does not vary more than 1°C over a period of 30 min or ±2% of the observed temperature rise of the motor for 3 consecutive readings at 30 min intervals.

Total loss—the difference between the input and the output.

Windage-friction loss—the mechanical losses due to bearing friction and windage.

3. General Requirements and Reference Publications

3.1 General Requirements

The construction of induction motors to be tested to this Standard shall comply with the following CSA Standards:

(a) C22.2 No. 100;
(b) C22.2 No. 77 (where applicable); and
(c) C22.2 No. 145: Class I, Groups C and D; Class II, Groups E, F and G (where applicable).

3.2 Reference Publications

This Standard refers to the following publications and where such reference is made it shall be to the edition listed below, including all amendments published thereto:

CSA Standards
C22.2 No. 77-1988,
Motors with Inherent Overheating Protection;

C22.2 No. 100-92,
Motors and Generators;

C22.2 No. 145-M1986 (R1992),
Motors and Generators for Use in Hazardous Locations.

IEEE* Standards
112-1991,
Polyphase Induction Motors and Generators;

120-1989,
Electrical Measurements in Power Circuits.

**Institute of Electrical and Electronics Engineers.*

4. General Test Requirements—Electrical Measurements

4.1 Unit of Measure

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

4.2 Power Supply

The source of supply should closely approach sine waveform and should provide balanced phase voltages. The voltage waveform deviation factor should not exceed 10% (see Clause 4.6, Note 1). The frequency shall be maintained within ±0.5% of the value required for the test being conducted, unless otherwise specified (see Clause 4.6, Note 2).

4.3 Frequency

Rapid changes in frequency cannot be tolerated on input-output tests, since such variations are transmitted to the output measuring devices. Any departure from rated frequency directly affects the efficiency obtained by using Method (1) (see Clause 5).

4.4 Instrument Selection

The indicating instruments used in 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. The indicating instrument shall be calibrated to limit errors to no greater than ±0.5% of full scale deflection traceable to national standards, within the last 12 months (see Clause 4.6, Note 3).

Digital readout or computer printout instruments capable of the equivalent accuracy of measurement may be used.

4.5 Instrument Transformers

When current and potential instrument transformers are used, corrections shall be made, when necessary, for ratio errors in voltage and current measurements, and for ratio and phase-angle errors in power measurements (see Clause 4.6, Note 3). The errors of instrument transformers shall be no greater than 0.5%.

4.6 Voltage

The voltages shall be read at the motor terminals. Tests should be made only when the voltage unbalance and the variation from rated voltage does not exceed ±0.5%. The per cent of voltage unbalance equals 100 times the maximum voltage deviation from the average voltage divided by the average voltage (see Note 2).

Notes:

(1) *Deviation Factor of a Wave. 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.*

(2) *Deviations from sine wave form, balanced supply voltage, and rated frequency will result in the motor having greater losses and lower efficiency and should be avoided.*

(3) *Further information regarding the use of instruments is given in IEEE Standard 120.*

4.7 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 motor performance from the test data.

4.8 Power Input

Power input to a three-phase motor 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 should 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.

4.9 Power Output

Mechanical power output measurements shall be made with the greatest of care and accuracy. If dynamometer measurements are used, coupling and bearing friction plus inertia errors should be compensated for (see Appendix C). Properly sized dynamometers shall be used, such that the coupling and friction losses of the dynamometer, measured at the rated speed of the motor being tested, shall not be greater than 15% of the rated output of the motor being tested. Calibrated shafts with torque deflection may be used to determine power output.

4.10 Performance Requirements
Polyphase, squirrel cage, single-speed, NEMA/EEMAC Design A or B induction motors with continuous ratings, within the scope of this Standard, shall meet or exceed the nominal efficiency values specified in Table 2 at either 75 or 100% of the rated load, when tested in accordance with Method 1 (see Clauses 5.1 and 6.1).

5. Test Methods

5.1 Method (1): Input-Output Method with Indirect Measurement of the Stray-Load Loss and Direct Measurement of the Stator Winding (I^2R), Rotor Winding (I^2R), Core and Windage-Friction Losses

5.1.1
Install thermocouples or other temperature-measuring devices in the motor in or on the winding-end heads or in the slots out of the cooling air circulation path, and measure and record the following:
(a) the motor stator line resistance; and
(b) the winding temperature.

5.1.2
Apply rated voltage, frequency, and full load to the motor until thermal equilibrium is reached. When constant winding temperature is reached under full load conditions, shut off the power supply, and within the time interval indicated in the following table disconnect the motor leads, and measure and record the following:
(a) the stator line resistance;
(b) the winding temperature; and
(c) the ambient temperature.*

**For motors with heat exchangers and an outside cooling medium, ambient temperature is the temperature of the cooling air at the motor's air inlet.*

Rating, kW	Time delay after switching off power, s
37.5 and less	30
Over 37.5 to 150	90
Above 150	120

If the time delay given by the above table is exceeded, plot a cooling curve based on the resistance across one pair of terminals with at least five points plotted at 60 s intervals to determine the values for the time delays given in the table.

5.1.3
Apply rated voltage and frequency to the motor, and load the motor to four load points approximately equally spaced between not less than 25% load and up to and including 100% load, and two load points suitably chosen above 100% load but not exceeding 150% load. When loading the motor, start at the highest load value and move in descending order to the lowest.

At each of the six points, measure and record the
(a) torque output corrected;*
(b) observed power input;
(c) average line current (A);
(d) speed (r/min);
(e) average winding temperature at that point;
(f) ambient temperature†; and
(g) average motor terminal voltage.

*Correct dynamometer torque reading as described in Appendix C.

†For motors with heat exchangers and an outside cooling medium, ambient temperature is the temperature of the cooling air at the motor's air inlet. Torque output should be corrected for dynamometer correction as described in Appendix C.

5.1.4
Disconnect the motor from the load and apply rated voltage and frequency to the motor until the no-load loss is stabilized. The no-load loss is stabilized when the no-load power input varies by 3% or less, when measured at two successive 30 min intervals.

5.1.5
When the motor has been disconnected from the load, apply power at rated frequency to the motor, at three or more values of voltage approximately equally spaced between 125% and 60% of rated voltage and three or more values of voltage approximately equally spaced between 50% of rated voltage down to approximately 20% of rated voltage, or to a point where the line current reaches a minimum value or becomes unstable.

At each of the voltage values, measure and record the
(a) average applied voltage;
(b) average line current;
(c) no-load power input; and
(d) average winding temperature at that point.

5.1.6
Calculate the stator winding (I^2R) loss at each of the six load points measured in Clause 5.1.3, using the equation

Stator winding (I^2R) loss = $0.0015\ I^2R_s$ (kW)
where
I = average line current as measured in Clause 5.1.3(c)
R_s = average line resistance as measured in Clause 5.1.1(a) corrected to winding temperature in Clause 5.1.3(e) as follows:

$$R_s = R_t\left(\frac{t_s + K}{t_t + K}\right)$$

where
R_t = test value of winding resistance (Ω) (see Clause 5.1.1(a))
t_s = winding temperature (°C) (see Clause 5.1.3(e))
t_t = temperature of winding when resistance was measured (°C) (see Clause 5.1.1(b))
K = 234.5 for pure copper

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

Note: *For other winding materials a suitable value of K should be used.*

5.1.7

Calculate the core loss and the windage-friction loss from no-load tests prescribed in Clause 5.1.5 as detailed below:

(a) the core loss and the windage-friction loss are considered to be independent of load for Methods (1) and (2), and the values calculated at no load can be used at each of the six load points in Clause 5.1.3;

(b) for each of the values of voltage given in Clause 5.1.5, subtract from the no-load power input readings (see Clause 5.1.5(c)) the no-load stator winding (I^2R) loss calculated as follows:

No-load stator winding (I^2R) loss = $0.0015\ I^2R_s$ (kW)

where

I = no-load line current (see Clause 5.1.5(b))

R_s = average line resistance as measured in Clause 5.1.1(a) corrected to winding temperature in Clause 5.1.5(d) as follows:

$$R_s = R_t\left(\frac{t_s + K}{t_t + K}\right)$$

where

R_t = test value of winding resistance (Ω) (see Clause 5.1.1(a))

t_s = winding temperature (°C) (see Clause 5.1.5(d))

t_t = temperature of winding when resistance was measured (°C) (see Clause 5.1.1(b))

K = 234.5 for pure copper

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

Note: *For other winding materials a suitable value of K should be used.*

(c) for each of the values of voltage between 125% and 60%, plot a curve of the no-load power input readings minus the no-load stator winding (I^2R) loss as calculated in Clause 5.1.7(b), against voltage. This curve then represents the core loss plus the windage-friction loss plotted against the voltage;

(d) for each of the values of voltage between 50% of rated volts and 20% of rated volts or to a point where the line current reaches a minimum value, plot the no-load power readings minus the no-load stator winding (I^2R) loss, as calculated in Clause 5.1.7(b), against the voltage squared. Determine the windage-friction loss by extrapolating this straight line to zero voltage; and

(e) from the curve in Clause 5.1.7(c), obtain, at 100% of rated voltage, the no-load power input reading minus the no-load stator winding (I^2R) loss. Subtract from this value the windage-friction loss (see Clause 5.1.7(d)) to determine the core loss.

5.1.8

Calculate the rotor winding (I^2R) loss at each of the six load points measured in Clause 5.1.3 using the equation:

Rotor winding (I^2R) loss = (measured power input)
(see Clause 5.1.3(b))—stator winding (I^2R) loss
(see Clause 5.1.6)—core loss (see Clause 5.1.7(e)) × slip

where
slip is per unit of synchronous speed

$$\text{Slip} = \frac{\text{synchronous speed} - \text{measured speed (see Clause 5.1.3(d))}}{\text{synchronous speed}}$$

5.1.9
Calculate the stray-load loss at each of the six load points measured in Clause 5.1.3 by first calculating the residual kilowatts as follows:
Residual kilowatts = power input (see Clause 5.1.3(b)) – power output (as calculated from torque (see Clause 5.1.3(a)) and speed (see Clause 5.1.3(d))) – stator winding (I^2R) loss (see Clause 5.1.6) – core loss (see Clause 5.1.7(e)) – windage-friction loss (see Clause 5.1.7(d)) – rotor winding (I^2R) loss (see Clause 5.1.8)
Note:

$$\textit{Power output (kilowatts)} = \frac{\textit{torque}\ (\mathrm{N{\cdot}m}) \times \mathrm{r/min}}{9549}$$

Smooth the residual power output (kW) data by using a linear regression analysis:
Residual power output (kW) = $AT^2 + B$

where
T = torque output (see Clause 5.1.3(a))
A = slope
B = intercept

If correlation coefficient q is less than 0.9, delete the worst point and recalculate A and B. If this increases, ie, $\gamma > 0.9$, use the second calculation; if not, 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 repeated.

When the A (slope constant) is established from the above, stray-load loss for each of the six points in Clause 5.1.3 can be calculated by using the equation

Stray-load loss = AT

where
T = torque output (from Clause 5.1.3(a))
A = slope (from Clause 5.1.9)

5.1.10
Calculate stator winding (I^2R) loss corrected to the temperature as measured in Clause 5.1.2 and to 25°C ambient temperature for each of the six load points measured in Clause 5.1.3 using the equation

Temperature corrected stator winding (I^2R) loss = $0.0015\ I^2R_s$ (kW)

where
I = average line current as measured in Clause 5.1.3(c)
R_s = average stator line resistance as measured in Clause 5.1.2(a) corrected to an ambient temperature of 25°C as follows:

$$R_s = R_t \left(\frac{t_s + K}{t_t + K} \right)$$

where
R_t = average stator line resistance as measured in Clause 5.1.2(a)
t_s = winding temperature (°C) as measured in Clause 5.1.2(b) corrected to 25°C ambient temperature (t_s = 5.1.2(b) + 25°C – 5.1.2(c))
t_t = temperature of winding when resistance was measured (°C), as measured in Clause 5.1.2(b)
K = 234.5 for pure copper
K = 225 for aluminum based on a volume conductivity of 62%

5.1.11
Calculate the rotor winding (I^2R) loss corrected to the temperature as measured in Clause 5.1.2 and to 25°C ambient temperature for each of the six load points in Clause 5.1.3 using the equation

Temperature corrected rotor winding (I^2R) loss = (measured power input (see Clause 5.1.3(b)) – temperature corrected stator winding (I^2R) loss (see Clause 5.1.10) – core loss (see Clause 5.1.7(e)) × slip (corrected)

where

$$\text{Slip(corrected)} = S \left(\frac{t_s + K}{t_t + K} \right)$$

where
slip (corrected) = slip per unit of synchronous speed corrected to the stator winding temperature in Clause 5.1.2(b) corrected to 25°C ambient temperature
S = slip per unit of synchronous speed from the speed as measured in Clause 5.1.3(d) and previously calculated in Clause 5.1.8
t_s = stator winding temperature as measured in Clause 5.1.2(b) corrected to 25°C ambient temperature (t_s = 5.1.2(b) + 25°C – 5.1.2(c))
t_t = observed stator winding temperature as measured in Clause 5.1.3(e)
K = 234.5 for pure copper
K = 225 for aluminum based on a volume conductivity of 62%

5.1.12
Calculate the power output temperature corrected at each of the six load points in Clause 5.1.3 using the equation

Power output (temperature corrected) = power input (at test point) – losses (corrected)

where
power input (at test point) = as measured in Clause 5.1.3(b)
losses (corrected) = core loss (Clause 5.1.7(e)) + windage-friction loss (Clause 5.1.7(d)) + stray-load loss (Clause 5.1.9) + temperature corrected stator winding (I^2R) loss

(Clause 5.1.10) + temperature corrected rotor winding (I^2R) loss (Clause 5.1.11)

5.1.13
Calculate the efficiency at each of the six load points in Clause 5.1.3 using the equation

$$\text{Efficiency} = \frac{\text{power output (temperature corrected)}}{\text{power input (at test point)}}$$

where power output (temperature corrected) is as calculated in Clause 5.1.12 and power input (at test point) is as measured in Clause 5.1.3 (b).

5.1.14
Determine the efficiency at precise load points by plotting efficiency using values calculated in Clause 5.1.13 against the power output (temperature corrected) calculated in Clause 5.1.12.

5.2 Method (2): Input Measurement Method with Direct Measurement of All Losses
Proceed as in Method (1) but omit torque output reading (see Clause 5.1.3(a)); and omit the indirect measurement of stray-load loss (see Clause 5.1.9) and substitute the direct measurement of stray-load loss as described in Clause 5.3.4.2 of IEEE Standard 112.
Note: *For other than motor rated power* (kW) *output, stray-load loss can be considered to vary directly as the square of the stator current at the load being considered minus the square of the no-load stator (A).*

5.3 Method (3): Equivalent Circuit Calculations with Direct Measurement of Core Loss, Windage-Friction Loss, and Stray-Load Loss
This method is as detailed in IEEE Standard 112, Clause 5.2.3.2, Method F.

6. Variations

6.1 Method (1) without Heat Run or Winding Temperature Measurement

6.1.1
If the rated temperature as specified in Clause 5.1.2 has not been measured and the winding temperature measuring devices not installed, machine efficiency may be determined using the following method.

6.1.2
Proceed as described in Clause 5.1.1 but omit winding temperature, and measure and record the ambient temperature.

6.1.3
Omit Clause 5.1.2.

6.1.4
Proceed as described in Clause 5.1.3 but omit winding temperature.

6.1.5
Omit Clause 5.1.4.

6.1.6
Proceed as described in Clause 5.1.5 but omit winding temperature and after shutting off the

power supply and quickly disconnecting the motor leads, measure and record the average stator line resistance.

6.1.7
Proceed as described in Clause 5.1.6 but in calculating the stator winding (I^2R) loss use the average winding resistance of the values measured in Clauses 6.1.2 and 6.1.6.

6.1.8
Proceed as described in Clause 5.1.7 but in calculating the stator winding (I^2R) loss use the average winding resistance of the values measured in Clauses 6.1.2 and 6.1.6.

6.1.9
Proceed as described in Clause 5.1.8.

6.1.10
Proceed as described in Clause 5.1.9.

6.1.11
Proceed as described in Clause 5.1.10 but correct the stator winding resistance from the value as measured at ambient temperature in Clause 6.1.2 to the temperature value as listed in Table 1 for the motor's rated class of insulation.

6.1.12
Proceed as described in Clause 5.1.11 but correct the slip determined from the speed at ambient temperature initially measured in Clause 6.1.4 to the temperature value as listed in Table 1 for the motor's rated class of insulation.

6.1.13
Proceed as described in Clause 5.1.12 but calculate the losses (corrected) using the appropriate values from Clauses 6.1.7 to 6.1.12.

6.1.14
Proceed as described in Clause 5.1.13 but use the value of power output (temperature corrected) as calculated in Clause 6.1.13.

6.1.15
Determine the motor efficiency as described in Clause 5.1.14 but use the values as calculated in Clauses 6.1.13 and 6.1.14.

6.2 Method (2) without Heat Run or Winding Temperature Measurement
Proceed as described in the revised Method (1) detailed in Clause 6.1 but omit torque output reading (see Clause 6.1.4); and omit Clause 6.1.10, and proceed as described in Clause 5.2.

6.3 Estimated Stray-Load Loss
If in Method (2) and (3) the direct measurement of stray-load loss has not been done, an estimate of stray-load loss as specified below shall be used:

Motor output, kW	Stray load loss estimate, kW
Greater than 37.5 to 150	0.018 × motor rated power output
Greater than 150 to 600	0.015 × motor rated power output
Greater than 600 to 1875	0.012 × motor rated power output
Greater than 1875	0.009 × motor rated power output

For other than motor rated kilowatt output stray-load loss can be considered to vary directly as the square of the stator amperes at the load being considered minus the square of the no-load stator amperes.

6.4 Core Loss and Windage-Friction Loss

Core loss (Wh) and windage-friction loss (WF) at 100% of rated voltage may be calculated, without plotting curves as described in Clause 5.1.7, as follows:

(a) take no-load motor measurements as described in Clause 5.1.5 at 100% of rated voltage;

(b) obtain the sum of core loss and windage-friction loss (Wh + WF) at 100% of rated voltage by subtracting the no-load stator winding (I^2R) loss according to Clause 5.1.7(b) from the no-load power reading from Clause 6.4(a);

(c) determine the windage-friction loss by calculating the Wh + WF loss for each of the voltage values below 50% volts and determine WF by using a linear regression analysis as follows:

$$(Wh + WF) = AV^2 + WF$$

where

(Wh + WF) = sum of core loss and windage-friction loss
A = slope
V = voltage
WF = windage-friction loss (intercept)

(d) determine core loss at 100% of rated voltage by subtracting WF as determined in Clause 6.4(c) from Wh + WF as determined in Clause 6.4(b).

Note: *This reference temperature should be used for determining the stator winding (I^2R) and rotor winding (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 corrected should be that of the lower insulation class.*

7. Test Record: Methods (1) and (2)

7.1 Initial Measurements

(Refer to Clause 5.1.1.)

(a) stator line resistance (Ω) =

(b) winding temperature (°C) =

7.2 Heat Run Measurements

(Refer to Clause 5.1.2.)

(a) stator line resistance (Ω) =
(b) winding temperature (°C) =
(c) ambient temperature (°C) =

7.3 Load Readings

(Refer to Clause 5.1.3.)

Test Points	1	2	3	4	5	6
(a) torque output (corrected)* (N•m)						
(b) power input (kW)						
(c) line current (A)						
(d) speed (r/min)						
(e) winding temperature (°C)						
(f) ambient temperature (°C)						
(g) line voltage (V)						

**Correct dynamometer torque reading as described in Appendix C.*

7.4 Core Loss Plus Windage-Friction Curve

(Refer to Clause 5.1.5.)

	Test points 125 to 60% voltage	Test points 50 to 20% voltage to instability point
(a) line voltage (V)		
(b) line current (A)		
(c) power input (kW)		
(d) winding temperature (°C)		

8. Marking

8.1

The nominal efficiency at 100% of the rated load (full-load) shall be marked on the motor in accordance with Clause 9. Where 75% of the rated load is used to meet the requirements of Clause 4.10, then the nominal efficiency at this load point shall also be marked.

9. Determining Nominal Efficiency

9.1

The nominal efficiency value shall be selected from Column A in Table 3 when the motor operates at its rated voltage, frequency, and related load point, and shall be not greater than the average efficiency of a large population of motors of the same design. The actual motor efficiency value shall be not less than the associated minimum value specified in Column B.

Table 1
Rated Full Load Temperature
(See Clause 6.1.1 and 6.1.2.)

Insulation	Temperature, °C
A	75
B	95
F	115
H	130

Table 2
Minimum Nominal Efficiency (January 1996)
(See Clause 4.10.)

	Open Motors				Enclosed motors			
Number of poles	**8**	**6**	**4**	**2**	**8**	**6**	**4**	**2**
Motor horsepower								
1	74.0	80.0	82.5	75.5	74.0	80.0	82.5	75.5
1.5	75.5	84.0	84.0	82.5	77.0	85.5	84.0	82.5
2	85.5	85.5	84.0	84.0	82.5	86.5	84.0	84.0
3	86.5	86.5	86.5	84.0	84.0	87.5	87.5	85.5
5	87.5	87.5	87.5	85.5	85.5	87.5	87.5	87.5
7.5	88.5	88.5	88.5	87.5	85.5	89.5	89.5	88.5
10	89.5	90.2	89.5	88.5	88.5	89.5	89.5	89.5
15	89.5	90.2	91.0	89.5	88.5	90.2	91.0	90.2
20	90.2	91.0	91.0	90.2	89.5	90.2	91.0	90.2
25	90.2	91.7	91.7	91.0	89.5	91.7	92.4	91.0
30	91.0	92.4	92.4	91.0	91.0	91.7	92.4	91.0
40	91.0	93.0	93.0	91.7	91.0	93.0	93.0	91.7
50	91.7	93.0	93.0	92.4	91.7	93.0	93.0	92.4
60	92.4	93.6	93.6	93.0	91.7	93.6	93.6	93.0
75	93.6	93.6	94.1	93.0	93.0	93.6	94.1	93.0
100	93.6	94.1	94.1	93.0	93.0	94.1	94.5	93.6
125	93.6	94.1	94.5	93.6	93.6	94.1	94.5	94.5
150	93.6	94.5	95.0	93.6	93.6	95.0	95.0	94.5
200	93.6	94.5	95.0	94.5	94.1	95.0	95.0	95.0

Table 3
Nominal Efficiency Tolerance
(See Clause 9.)

Column A Nominal efficiency	Column B Minimum efficiency based on 20% loss difference
99.0	98.8
89.9	98.7
98.8	98.6
98.7	98.5
98.6	98.4
98.5	98.2
98.4	98.0
98.2	97.8
98.0	97.6
97.8	97.4
97.6	97.1
97.4	96.8
97.1	96.5
96.8	96.2
96.5	95.8
96.2	95.4
95.8	95.0
95.4	94.5
95.0	94.1
94.5	93.6
94.1	93.0
93.6	92.4
93.0	91.7
92.4	91.0
91.7	90.2
91.0	89.5
90.2	88.5
89.5	87.5
88.5	86.5
87.5	85.5

(continued)

Table 3 (Concluded)

Column A Nominal efficiency	Column B Minimum efficiency based on 20% loss difference
86.5	84.0
85.5	82.5
84.0	81.5
82.5	80.0
81.5	78.5
80.0	77.0
78.5	75.5
77.0	74.0
75.5	72.0
74.0	70.0
72.0	68.0
70.0	66.0
68.0	64.0
66.0	62.0
64.0	59.5
62.0	57.5
59.5	55.0
57.5	52.5
55.0	50.5
52.5	48.0
50.5	46.0

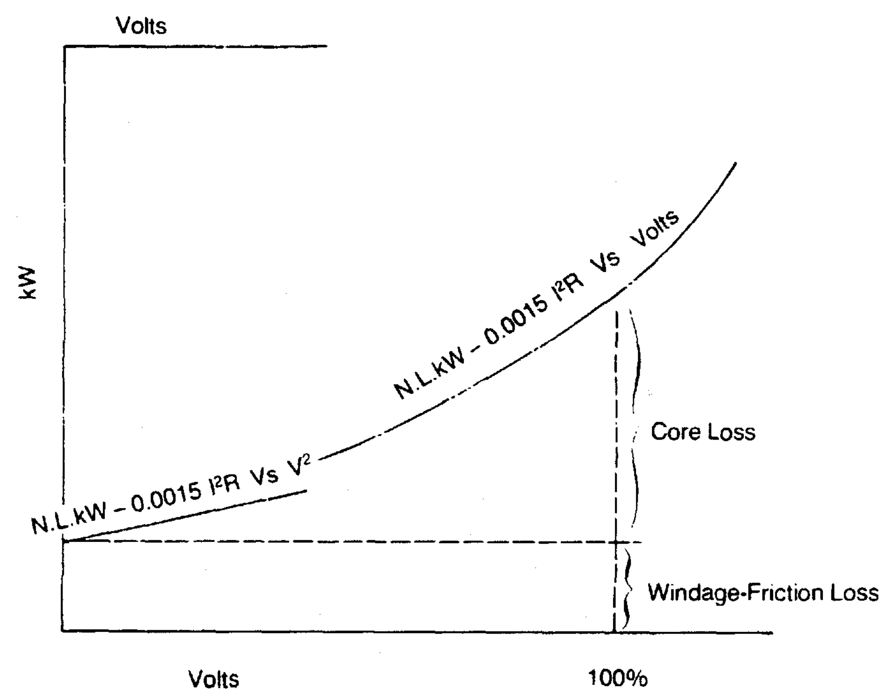

Figure 1
Core Loss and Windage-Friction Loss versus Voltage and Voltage Square Curves

Figure 2
Form for Calculation of Motor Efficiency: Methods (1) and (2)

		1	2	3	4	5	6
1.	Test point	1	2	3	4	5	6
2.	Power input (kW)(Clause 5.1.3(b))						
3.	Stator winding (I^2R) loss (kW) at test temperature (Clause 5.1.6 calculations)						
4.	Core loss (kW)(Clause 5.1.7(e) calculations)						
5.	Winding-friction loss (kW) (Clause 5.1.7(d) calculations)						
6.	Rotor winding (I^2R) loss (kW) at test temperature (Clause 5.1.9 calculations)						
7.	Stray-load loss (kW)(Clause 5.1.9 calculations)						
8.	Temperature corrected stator winding (I^2R) loss (kW)(Clause 5.1.10 calculations)						
9.	Temperature corrected rotor winding (I^2R) loss (kW)(Clause 5.1.11 calculations)						
10.	Temperature corrected power output (kW) (Clause 5.1.12)						

11. Efficiency % =

$$\frac{[(10)\ \text{Temperature Corrected Power Output}]}{[(2)\ \text{Power Input}]} \times 100$$

Appendix A
Guidelines for Determining the Energy Efficiency

Note: *This Appendix is not a mandatory part of the Standard.*

A1. Scope

A1.1 General
Appendix A is a guide to help manufacturers carry out the calculations as required by the mandatory clauses for Method (1) described in the Standard. It has the same clause numbers (with the prefix "A") as the mandatory clauses.

Appendix A does not restrict or specify the means for making the calculations. The mandatory clauses in the Standard specify what is required and allow manufacturers to use the most suitable means for their situation.

The specific example given in this Guideline is nonmandatory.

A5.1 Method (1): Input-Output Method with Indirect Measurement of the Stray-Load Loss and Direct Measurement of the Stator Winding (I^2R), Rotor Winding (I^2R), Core and Windage-Friction Losses

A5.1.1 Initial Measurements
A motor with: 10 hp, 1800 r/min, 575 V, three-phases, and 60 Hz was tested and the following measurements were taken:
(a) stator line resistance = 1.650 Ω;
(b) winding temperature = 18°C.

A5.1.2 Heat Run Measurements
After constant winding temperatures had been reached with the motor operating under full load, and at rated voltage and frequency, the following measurements were taken:
(a) stator line resistance = 2.17 Ω;
(b) winding temperature = 108°C;
(c) ambient temperature = 29°C.

A5.1.3 Load Point Measurements
Under the six different load points the following measurements were taken:

Test Points	1	2	3	4	5	6
(a) torque output (corrected)*	50.8	46.8	40.7	30.5	20.3	10.2
(b) power input (kW)	10.98	10.15	8.88	6.78	4.73	2.71
(c) line current	13.76	12.90	11.61	9.66	8.03	6.81
(d) speed (r/min)	1755	1757	1763	1772	1782	1790
(e) winding temperature (°C)	37	45	48	48.5	49	49
(f) ambient temperature (°C)	20	20	20	20	20	20
(g) line voltage	575	575	575	575	575	575

**To correct for dynamometer losses see Appendix C. Add* 0.08 N•m *to the observed torque output value.*

A5.1.5 Core Loss Plus Windage-Friction Measurements
Under no load the following measurements were taken at the various voltage points as indicated:

	Test points 125 to 60% voltage				Test Points 50 to 20% voltage to instability point		
(a) line voltage	603.7	575	517.5	287.5	230	172.5	126
(b) line current	7.35	6.32	4.92	2.38	1.94	1.51	1.193
(c) power input (kW)	0.860	0.720	0.540	0.200	0.156	0.120	0.096
(d) winding temperature (°C)	54	54	54	52	50	49	48

A5.1.6

The stator winding (I^2R) loss at each of the six load points is calculated as follows:
Stator winding (I^2R) loss = 0.0015 I^2R_s (kW)
where

$$R_s = R_t \left(\frac{t_s + K}{t_t + K}\right)$$

From the measurements in Clause A5.1.1:
R_t = 1.650 Ω
t_t = 18°C
t_s = the temperature values as measured in Clause A5.1.3(e).

First, calculate the values of R_s for each of the load points:

$$1.650 \times \frac{37 + 234.5}{18 + 234.5} = 1.77(\Omega)$$

$$1.650 \times \frac{45 + 234.5}{18 + 234.5} = 1.83(\Omega)$$

$$1.650 \times \frac{48 + 234.5}{18 + 234.5} = 1.85(\Omega)$$

$$1.650 \times \frac{48.5 + 234.5}{18 + 234.5} = 1.85(\Omega)$$

$$1.650 \times \frac{49 + 234.5}{18 + 234.5} = 1.85(\Omega)$$

$$1.650 \times \frac{49 + 234.5}{18 + 234.5} = 1.85(\Omega)$$

Then calculate the stator winding (I^2R) loss for each of the load points:
$0.0015 \times (13.76)^2 \times 1.77 = 0.503$ (kW)
$0.0015 \times (12.9)^2 \times 1.83 = 0.457$ (kW)
$0.0015 \times (11.61)^2 \times 1.85 = 0.374$ (kW)
$0.0015 \times (9.66)^2 \times 1.85 = 0.259$ (kW)
$0.0015 \times (8.03)^2 \times 1.85 = 0.179$ (kW)
$0.0015 \times (6.81)^2 \times 1.85 = 0.129$ (kW)

Summary:

Test Points	1	2	3	4	5	6
Stator I^2R loss (kW)	0.503	0.457	0.374	0.259	0.179	0.129

A5.1.7
The core loss and the windage-friction loss from the no-load tests are determined as follows:

Step 1
Calculate the no-load stator winding (I^2R) loss for each of the voltage points as follows:
No-load stator winding (I^2R) loss = 0.0015 I^2R_s (kW)

where

$$R_s = R_t\left(\frac{t_s + K}{t_t + K}\right)$$

R_t = 1.650
t_t = 18°C
t_s = the values as measured in Clause A5.1.5(d)

First, calculate the values of R_s for each of the voltage points:

$$1.650 \times \frac{54 + 234.5}{18 + 234.5} = 1.89(\Omega)$$

$$1.650 \times \frac{54 + 234.5}{18 + 234.5} = 1.89(\Omega)$$

$$1.650 \times \frac{54 + 234.5}{18 + 234.5} = 1.89(\Omega)$$

$$1.650 \times \frac{52 + 234.5}{18 + 234.5} = 1.87(\Omega)$$

$$1.650 \times \frac{50 + 234.5}{18 + 234.5} = 1.86(\Omega)$$

$$1.650 \times \frac{49 + 234.5}{18 + 234.5} = 1.85(\Omega)$$

$$1.650 \times \frac{48 + 234.5}{18 + 234.5} = 1.85(\Omega)$$

Then calculate the no-load stator winding (I^2R) loss for each of the voltage points.
$0.0015 \times (7.35)^2 \times 1.89 = 0.153$ (kW)
$0.0015 \times (6.32)^2 \times 1.89 = 0.113$ (kW)
$0.0015 \times (4.92)^2 \times 1.89 = 0.0686$ (kW)

$0.0015 \times (2.38)^2 \times 1.87 = 0.0159$ (kW)
$0.0015 \times (1.94)^2 \times 1.86 = 0.0105$ (kW)
$0.0015 \times (1.51)^2 \times 1.85 = 0.006\,33$ (kW)
$0.0015 \times (1.193)^2 \times 1.85 = 0.003\,95$ (kW)

Step 2
Calculate the core loss and windage-friction loss for each of the voltage points:
Core loss and windage-friction loss = no-load power input – no-load stator winding (I^2R) loss

0.860 – 0.153 = 0.707 (kW)
0.720 – 0.113 = 0.607 (kW)
0.540 – 0.0686 = 0.471 (kW)
0.200 – 0.0159 = 0.184 (kW)
0.156 – 0.0105 = 0.146 (kW)
0.120 – 0.006 33 = 0.114 (kW)
0.096 – 0.003 95 = 0.0921 (kW)

Step 3
Plot a curve using the following core loss and windage-friction loss (kW) values for the "Y" ordinates and the associated voltage points for the "X" ordinates (see Figure A1):

X (V)	Y (kW)
603.75	0.707
575	0.607
517.5	0.471

Step 4
Plot a second curve using the following core loss and windage-friction loss (kW) values for the "Y" ordinates and the associated voltage points squared for the "X" ordinates (see Figure A1):

Voltage point	X (V^2)	Y (kW)
287.5	82 700	0.184
230	52 900	0.146
172.5	29 800	0.114
126	15 900	0.0921

Step 5
Extrapolate the second curve, which is a straight line, to the zero voltage axis. The kilowatt value at this "Y" intercept is the windage-friction loss, which is found to be 0.072 kW.

Step 6
Using the first curve, determine the "Y" ordinate corresponding to the "X" ordinate equal to the rated voltage of the motor. In this example, X = 575 V and Y = 0.607 kW.
The core loss is found by subtracting the windage-friction loss from this "Y" value:
Core loss = 0.607 – 0.072 = 0.535 kW

A5.1.8

The rotor winding (I^2R) loss at each of the six load points is calculated as follows:
Rotor winding (I^2R) loss = (measured power input – stator winding (I^2R) loss – core loss) × slip

where

$$\text{slip} = \frac{\text{synchronous speed} - \text{measured speed}}{\text{synchronous speed}}$$

First, calculate the slip for each of the load points.

$$\frac{1800 - 1755}{1800} = 0.025 \text{ (slip)}$$

$$\frac{1800 - 1757}{1800} = 0.0239 \text{ (slip)}$$

$$\frac{1800 - 1763}{1800} = 0.0206 \text{ (slip)}$$

$$\frac{1800 - 1772}{1800} = 0.0156 \text{ (slip)}$$

$$\frac{1800 - 1782}{1800} = 0.010 \text{ (slip)}$$

$$\frac{1800 - 1790}{1800} = 0.00556 \text{ (slip)}$$

Then calculate the rotor winding (I^2R) loss for each of the load points:

$$(10.98 - 0.503 - 0.535) \times 0.025 = 0.249 \text{ (kW)}$$
$$(10.15 - 0.457 - 0.535) \times 0.0239 = 0.219 \text{ (kW)}$$
$$(8.88 - 0.374 - 0.535) \times 0.0206 = 0.164 \text{ (kW)}$$
$$(6.78 - 0.259 - 0.535) \times 0.0156 = 0.0934 \text{ (kW)}$$
$$(4.73 - 0.179 - 0.535) \times 0.01 = 0.0402 \text{ (kW)}$$
$$(2.71 - 0.129 - 0.535) \times 0.0055 = 0.0114 \text{ (kW)}$$

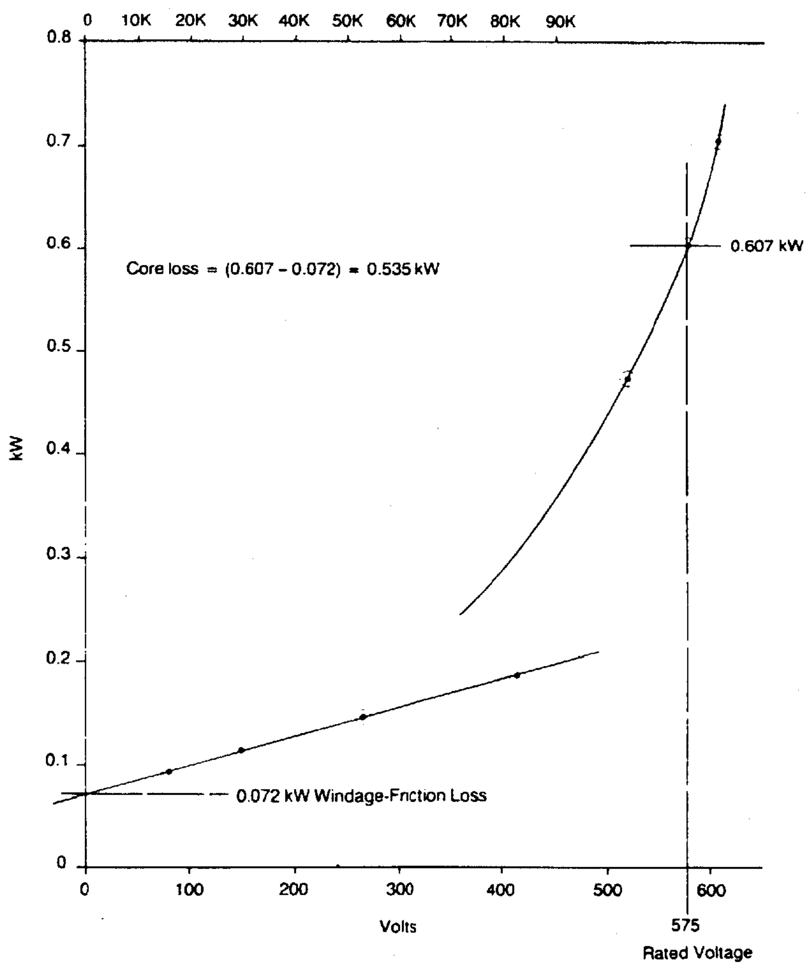

Figure A1
Core Loss and Windage-Friction Loss versus Voltage and Voltage Square Curves

A5.1.9
The stray-load loss at each of the six load points is calculated as follows:

Step 1
Calculate the residual power (kW) for each of the load points as follows:

Residual power = power input – power output – stator winding (I^2R) loss – core loss – windage-friction loss – rotor winding (I^2R) loss
where

$$\text{power output (kW)} = \frac{\text{torque (N} \bullet \text{m)} \times \text{speed (r/min)}}{9549}$$

First, calculate the power output for each of the load points:

$$\frac{50.8 \times 1755}{9549} = 9.34 \text{ (kW)}$$

$$\frac{46.8 \times 1757}{9549} = 8.61 \text{ (kW)}$$

$$\frac{40.7 \times 1763}{9549} = 7.51 \text{ (kW)}$$

$$\frac{30.5 \times 1772}{9549} = 5.66 \text{ (kW)}$$

$$\frac{20.3 \times 1782}{9549} = 3.79 \text{ (kW)}$$

$$\frac{10.2 \times 1790}{9549} = 1.91 \text{ (kW)}$$

Then calculate the residual power (kW) for each of the load points:

10.98 – 9.34 – 0.503 – 0.535 – 0.072 – 0.24 = 0.281 (kW)

10.15 – 8.61 – 0.457 – 0.535 – 0.072 – 0.219 = 0.257 (kW)
8.88 – 7.51 – 0.374 – 0.535 – 0.072 – 0.16 = 0.225 (kW)
6.78 – 5.66 – 0.259 – 0.535 – 0.072 – 0.093 = 0.161 (kW)
4.73 – 3.79 – 0.179 – 0.535 – 0.072 – 0.040 = 0.114 (kW)
2.71 – 1.91 – 0.129 – 0.535 – 0.072 – 0.011 = 0.0526 (kW)

Step 2
Smooth the residual power data by using a linear regression analysis as described in Appendix B to find the values of "A" and "B" in the following linear relationship:

Residual power = $AT^2 + B$

where
T = the torque output corrected as shown in Clause A5.1.3(a)
A = the slope of the line

B = the Y intercept of the line

As described in Appendix B, the values for this sample calculation were found to be as follows:

A = 0.000 087 9
B = 0.0664

Also, the correlation coefficient (γ) for this sample calculation was found to be 0.987, which, because it is greater than 0.9, indicates that the test data are satisfactory.

Step 3

Calculate the stray-load loss for each of the load points:
Stray-load loss = AT^2

$0.000\,087\,9 \times (50.8)^2 = 0.227$ (kW)
$0.000\,087\,9 \times (46.8)^2 = 0.193$ (kW)
$0.000\,087\,9 \times (40.7)^2 = 0.146$ (kW)
$0.000\,087\,9 \times (30.5)^2 = 0.0818$ (kW)
$0.000\,087\,9 \times (20.3)^2 = 0.0362$ (kW)
$0.000\,087\,9 \times (10.2)^2 = 0.009\,15$ (kW)

A5.1.10

The temperature corrected stator winding (I^2R) loss for each of the six load points is calculated as follows:
Temperature corrected stator winding (I^2R) loss = $0.0015\ I^2R_s$ (kW)

where

$$R_s = R_t\left(\frac{t_s + K}{t_t + K}\right)$$

ie, the stator line resistance (Ω) as measured in Clause A5.1.2(a) corrected to an ambient temperature of 25°C

R_t = 2.17 Ω, the stator line resistance (Ω) as measured in Clause A5.1.2(a)
t_t = 108°C, the temperature of winding when resistance was measured, according to Clause A5.1.2(b)
t_s = temperature value of Clause A5.1.2(b) + 25°C − temperature value of Clause A5.1.2(c)

This equation gives the value of the winding temperature as measured in Clause A5.1.2(b) corrected to 25°C.

t_s = 108 + 25 − 29 = 104°C

First, calculate the value of R_s:

$$R_s = 2.17\left(\frac{104 + 234.5}{108 + 234.5}\right) = 2.14\ \Omega$$

Then calculate the temperature corrected stator winding (I^2R) loss for each of the load points:

$0.0015 \times (13.76)^2 \times 2.14 = 0.608$ (kW)
$0.0015 \times (12.9)^2 \times 2.14 = 0.534$ (kW)
$0.0015 \times (11.61)^2 \times 2.14 = 0.433$ (kW)
$0.0015 \times (9.66)^2 \times 2.14 = 0.300$ (kW)

0.0015 × (9.66)^2 × 2.14 = 0.300 (kW)
0.0015 × (8.03)^2 × 2.14 = 0.207 (kW)
0.0015 × (6.81)^2 × 2.14 = 0.149 (kW)

A5.1.11
The temperature corrected rotor winding (I^2R) loss for each of the six load points is calculated as follows:
Temperature corrected rotor winding (I^2R) loss =(measured power input – temperature corrected stator winding (I^2R) loss – core loss) × slip (corrected)

where

$$\text{slip (corrected)} = S\left(\frac{t_s + K}{t_t + K}\right)$$

ie, the slip per unit of synchronous speed corrected to the stator winding temperature in Clause A5.1.2(b) corrected to an ambient temperature of 25°C
s = the slip per unit of synchronous speed from the speed as measured in Clause A5.1.3(d) and previously calculated in Clause A5.1.8
t_s = 108 + 25 – 29 = 104°C, ie, the stator winding temperature as measured in Clause A5.1.2(b) corrected to 25°C
t_t = the temperature values as measured in Clause A5.1.3(e)
First, calculate the slip (corrected) for each of the load points:

$$0.025 \times \frac{104 + 225}{37 + 225} = 0.0314 \text{ (slip corrected)}$$

$$0.0239 \times \frac{104 + 225}{45 + 225} = 0.0291 \text{ (slip corrected)}$$

$$0.0206 \times \frac{104 + 225}{48 + 225} = 0.0248 \text{ (slip corrected)}$$

$$0.0156 \times \frac{104 + 225}{48.5 + 225} = 0.0188 \text{ (slip corrected)}$$

$$0.01 \times \frac{104 + 225}{49 + 225} = 0.0120 \text{ (slip corrected)}$$

$$0.005\ 56 \times \frac{104 + 225}{49 + 225} = 0.006\ 68 \text{ (slip corrected)}$$

Then calculate the temperature corrected rotor winding (I^2R) loss for each of the load points:
(10.98 – 0.608 – 0.535) × 0.0314 = 0.309 (kW)
(10.15 – 0.534 – 0.535) × 0.0291 = 0.264 (kW)
(8.88 – 0.433 – 0.535) × 0.0248 = 0.196 (kW)
(6.78 – 0.300 – 0.535) × 0.0188 = 0.112 (kW)
(4.73 – 0.207 – 0.535) × 0.0120 = 0.0479 (kW)
(2.71 – 0.149 – 0.535) × 0.006 68 = 0.0135 (kW)

A5.1.12

The temperature corrected power output for each of the six load points is calculated as follows:

Power output (temperature corrected) = power input (at test point) − losses (corrected)

where

power input (at test point) = the values as measured in Clause A5.1.3(b)

losses (corrected) = core loss (Clause A5.1.7(e)) + windage-friction loss (Clause A5.1.7(d)) + stray-load loss (Clause A5.1.9) + temperature corrected stator winding (I^2R) loss (Clause A5.1.10) + temperature corrected rotor winding (I^2R) loss (Clause A5.1.11)

Note: *All values are expressed in kilowatts.*

Calculate the power output (temperature corrected) for each of the load points.

10.98 − (0.535 + 0.072 + 0.227 + 0.608 + 0.309) = 9.24 (kW)
10.15 − (0.535 + 0.072 + 0.193 + 0.534 + 0.264) = 8.56 (kW)
8.88 − (0.535 + 0.072 + 0.146 + 0.433 + 0.196) = 7.50 (kW)
6.78 − (0.535 + 0.072 + 0.0818 + 0.300 + 0.112) = 5.68 (kW)
4.73 − (0.535 + 0.072 + 0.0362 + 0.207 + 0.0479) = 3.83 (kW)
2.71 − (0.535 + 0.072 + 0.009 15 + 0.149 + 0.0135) = 1.93 (kW)

A5.1.13

The efficiency for each of the six load points is calculated as follows:

$$\text{Efficiency} = \frac{\text{power output (temperature corrected)}}{\text{power input (at test point)}}$$

where

power output (temperature corrected) = the values as calculated in Clause A5.1.12

power input (at test point) = the values as measured in Clause A5.1.3(b)

Calculate the efficiency for each of the load points:

$$\frac{9.24}{10.98} = 0.842 \text{ (efficiency)}$$

$$\frac{8.56}{10.15} = 0.843 \text{ (efficiency)}$$

$$\frac{7.50}{8.88} = 0.845 \text{ (efficiency)}$$

$$\frac{5.68}{6.78} = 0.838 \text{ (efficiency)}$$

$$\frac{3.83}{4.73} = 0.810 \text{ (efficiency)}$$

$$\frac{1.93}{2.71} = 0.712 \text{ (efficiency)}$$

A5.1.14

Determine the efficiency at precise load points by plotting a curve using the efficiency values (calculated in Clause A5.1.13) for the "Y" ordinates and the associated power output (temperature corrected) values (calculated in Clause A5.1.12) for the "X" ordinates. (See Figure A2.) These values are tabulated as follows:

X (Power output (temperature corrected), kW)	Y (Per cent efficiency)
9.24	84.2
8.56	84.3
7.50	84.5
5.68	83.8
3.83	81.0
1.93	71.2

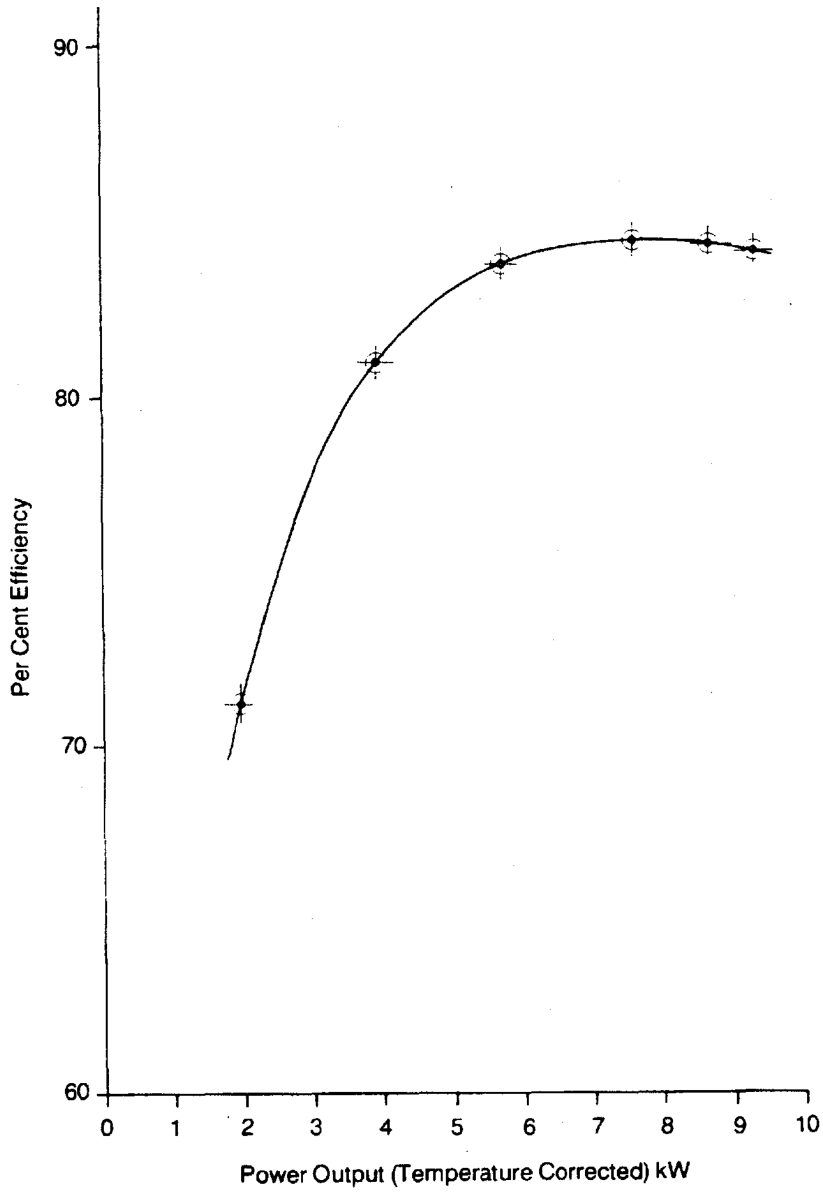

Figure A2
Efficiency versus Power Output Curve

Figure A3
Form for Calculation of Motor Efficiency: Method (1)

1. Test point	1	2	3	4	5	6
2. Power input (kW)(Clause A5.1.3(b))	10.98	10.15	8.88	6.78	4.73	2.71
3. Stator winding (I^2R) loss (kW) at test temperature (Clause A5.1.6 calculations)	0.503	0.457	0.374	0.259	0.179	0.129
4. Core loss (kW)(Clause A5.1.7(e) calculations)	0.535	0.535	0.535	0.535	0.535	0.535
5. Winding-friction loss (kW) (Clause A5.1.7(d) calculations)	0.072	0.072	0.072	0.072	0.072	0.072
6. Rotor winding (I^2R) loss (kW) at test temperature (Clause A5.1.9 calculations)	0.249	0.219	0.164	0.0934	0.0402	0.0114
7. Stray-load loss (kW)(Clause A5.1.9 calculations)	0.227	0.193	0.146	0.0818	0.0362	0.009 15
8. Temperature corrected stator winding (I^2R) loss (kW)(Clause A5.1.10 calculations)	0.608	0.534	0.433	0.300	0.207	0.149
9. Temperature corrected rotor winding (I^2R) loss (kW)(Clause A5.1.11 calculations)	0.301	0.258	0.192	0.109	0.0467	0.0132
10. Temperature corrected power output (kW) (Clause A5.1.12)	9.24	8.56	7.50	5.68	3.83	1.93
11. Efficiency % = $\frac{[(10)\ \text{Temperature Corrected Power Output}]}{[(2)\ \text{Power Input}]} \times 100$	84.2	84.3	84.5	83.8	81.0	71.2

Appendix B
Linear Regression Analysis

Note: *This Appendix is not a mandatory part of this Standard.*

B1. General Purpose

The purpose of linear regression analysis is to find a mathematical relationship between two sets of variables, so that the value of one variable can be used to predict the other. Linear regression assumes that the two variables are related linearly; that is, if paired values of the two variables (Xi, Yi) are plotted, the points will nearly fit a straight line. How well these paired values fit the line is indicated by the correlation coefficient (γ).

A straight-line linear relationship is expressed as:

$$Y = AX + B$$

where
Y = the dependent variable
X = the independent variable
A = the slope of the line
B = the Y intercept of the line

The slope of the line (A) and the Y intercept (B) are computed by the use of least-squares linear regression formulas as follows:

$$\text{(Slope) } A = \frac{N\,\Sigma XY - (\Sigma X)(\Sigma Y)}{N\,\Sigma X^2 - (\Sigma X)^2}$$

$$\text{(Y intercept) } B = \frac{\Sigma Y}{N} - A\,\frac{(\Sigma X)}{N}$$

where
N = the number of paired values of the two variables (Xi, Yi)

The correlation coefficient (γ) is computed by the use of the following formula:

$$\gamma = \frac{N\,\Sigma XY - (\Sigma X)\,(\Sigma Y)}{\sqrt{(N\Sigma X^2 - (\Sigma X)^2)\,(N\Sigma Y^2 - (\Sigma Y)^2)}}$$

Values of the correlation coefficient range from −1 to +1. A negative value indicates a negative relationship (eg, as X increases, Y decreases, or vice versa) and a positive value indicates a positive relationship (eg, as X increases, Y increases). The closer the value to −1 or +1, the better the relationship is. A correlation coefficient near zero indicates that no relationship exists.

B2. Linear Regression Analysis of Residual Power

The residual power (kW) is related to torque output (T) (N•m) (kW) by the linear relationship:
Residual power = $AT^2 + B$

where
residual power = the dependent variable (Y)
T^2 = the independent variable (X). It is also the torque output value squared (see Clause A5.1.3(a))
A = the slope of the line
B = the Y intercept of the line

With reference to the example data, the values for T, T^2 (or X), and residual power (or Y) are as follows:

Torque T =	50.8	46.8	40.7	30.5	20.3	10.2
T^2 (or X) =	2580	2190	1660	930	412	104
Residual power (Y) =	0.281	0.257	0.225	0.161	0.114	0.0526

The task is to calculate the values for A, B, and q using the least-squares linear regression formulas as previously described.

To accomplish this, the values to be used in the linear regression formulas first must be calculated. This is best done by making a tabulation and summing the columns as follows:

x (or T^2)	Y	X^2	Y^2	XY
2 580	0.281	6 660 000	0.079 0	725
2 190	0.257	4 800 000	0.066 0	563
1 660	0.225	2 760 000	0.050 6	374
930	0.161	865 000	0.025 9	150
412	0.114	170 000	0.013 0	47.0
104	0.052 6	10 800	0.002 77	5.47
$\Sigma X =$ 7 876	$\Sigma Y =$ 1.090 6	$\Sigma X^2 =$ 15 265 800	$\Sigma Y^2 =$ 0.237 27	$\Sigma MY =$ 1 864.47

Putting these summations into the linear regression formulas, the results are as follows:

$$\text{(Slope) } A = \frac{N\Sigma XY - (\Sigma X)(\Sigma Y)}{N\Sigma X^2 - (\Sigma X)^2} = \frac{(6)(1\,864.47) - (7876)(1.0906)}{(6)(15\,265\,800) - (7876)^2}$$

A = 0.000 087 9

$$\text{(Y intercept) } B = \frac{\Sigma Y}{N} - A\frac{(\Sigma X)}{N} = \frac{1.0906}{6} - (0.000\,087\,9)\,\frac{(7876)}{6}$$

B = 0.066 4

$$\text{(Correlation coefficient) } \gamma = \frac{N\Sigma XY - (\Sigma X)\,(\Sigma Y)}{\sqrt{(N\Sigma X^2 - (\Sigma X)^2)\,(N\Sigma Y^2 - (\Sigma Y)^2)}}$$

$$\gamma = \frac{(6)(1\,864.47) - (7876)(1.0906)}{\sqrt{(6)(15\,265\,800) - (7876)^2)((6)(0.237\,27) - (1.0906)^2)}} = 0.987$$

Because the correlation coefficient (γ) is close to +1, it indicates a very good relationship between the residual kilowatt and the torque output squared.

Appendix C
Procedure for Correction of Dynamometer Torque Readings

Note: *This Appendix is not a mandatory part of this Standard.*

C1.
Run the motor coupled to the dynamometer with the dynamometer not loaded.
Measure and record
(a) the power input (kW);
(b) the average line current (A);
(c) the speed (r/min);
(d) the torque output registered by dynamometer (N•m); and
(e) the average stator line resistance (power supply disconnected) (Ω);
Calculate

(f) $\text{slip} = \dfrac{\text{synchronous speed} - (\text{C1(c)})}{\text{synchronous speed}}$

(g) stator I^2R loss = (0.0015) $(\text{C1(b)})^2$ (C1(e)), (kW)

C2.
Run the motor uncoupled from the dynamometer.

Measure and record
(a) the power input, (kW);
(b) the average line current (A);
(c) the average stator line resistance (power supply disconnected) (Ω);
Calculate
(d) stator I^2R = (0.0015) $(\text{C2(b)})^2$ (C2(c)) (kW).

C3.
Calculate

Dynamometer torque correction =

$$\frac{k}{(\text{C1(c)})}((\text{C1(a)} - \text{C1(g)} - \text{core loss})(1 - \text{C1(f)}) - (\text{C2(a)} - \text{C2(d)} - \text{core loss})) - \text{C1(d)}$$

where
k = 9549 for torque, (N•m)
Core loss is as calculated in Clause 5.1.7.

C4.
Calculate corrected values of torque by adding dynamometer torque correction (C3) to observed values of torque.

Example:
With reference to the example data, motor input readings with the dynamometer coupled and uncoupled, and the calculated dynamometer torque correction are as follows:

C1.

Motor coupled to the dynamometer:

(a) power input = 1.52 kW
(b) average line current = 5.4 A
(c) speed (r/min) = 1795
(d) torque output registered by the dynamometer = 3.78 N•m
(e) average stator line resistance (power supply disconnected) = 2.17 Ω;

(f) slip (calculated) = $\frac{1800 - 1795}{1800} = 0.0027$;

(g) stator I^2R loss (calculated) = $0.0015 \times 5.4^2 \times 2.17 = 0.095$ kW

C2.

Motor uncoupled from the dynamometer

(a) power input = 0.780 kW
(b) average line current = 5.11 A
(c) average stator line resistance (power supply disconnected) = 2.12 Ω
(d) stator I^2R loss calculated = $0.0015 \times 5.11^2 \times 2.12 = 0.083$ kW

C3.

Dynamometer torque correction =

$$\frac{9549}{1795}[(1.52 - 0.095 - 0.535)(1 - 0.0027) - (0.780 - 0.083 - 0.535)] - 3.78 = 0.08 \text{ N•m}$$

C4.

Add the dynamometer torque correction (C3) to the observed values of torque (A5.1.3(a)).

Proposal for Change

To help our volunteer members to assess proposals to change requirements we recommend that each proposal for change be submitted in writing and identify the
(a) Standard number;
(b) Clause number;
(c) proposed wording of the Clause (requirement, test, or pass/fail criterion) using mandatory language and underlining those words changed from the existing Clause (if applicable); and
(d) rationale for the change, including all supporting data necessary to be considered.

The proposal should be submitted to the Standards Administrator at least one month prior to the next meeting of the Committee. It is CSA Committee practice that only those proposals sent out to members prior to a meeting can be the subject of discussion and action. This is to allow the members time to consider the proposal and to do any research they may feel necessary.

Date: ____ - ____ - ____
YY MM DD

To: The Standards Administrator of CSA Standard ______________________________

From: ______________________________

Affiliation: ______________________________

Address: ______________________________

____

Phone: ____________________ **Fax:** ____________________

Re: Request for an Amendment, Deletion, or Addition to Clause(s) ____________

Proposed change:

(Use reverse and additional pages as required.)