

Rotating electrical machines —

**Part 2-1: Standard methods for
determining losses and efficiency from
tests (excluding machines for traction
vehicles)**

ICS 29.160.01

National foreword

This British Standard is the UK implementation of EN 60034-2-1:2007. It is identical to IEC 60034-2-1:2007. It supersedes BS EN 60034-2:1999 which is declared obsolescent.

NOTE BS EN 60034-2:1999 is declared current and obsolescent rather than withdrawn in order to retain IEC 60034-24:1974 which is reproduced in Annex B of BS EN 60034-2:1999.

The UK participation in its preparation was entrusted to Technical Committee PEL/2, Rotating electrical machinery.

A list of organizations represented on this committee can be obtained on request to its secretary.

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**Rotating electrical machines -
Part 2-1: Standard methods for determining losses and efficiency
from tests (excluding machines for traction vehicles)
(IEC 60034-2-1:2007)**

Machines électriques tournantes -
Partie 2-1: Méthodes normalisées
pour la détermination des pertes
et du rendement à partir d'essais
(à l'exclusion des machines
pour véhicules de traction)
(CEI 60034-2-1:2007)

Drehende elektrische Maschinen -
Teil 2-1: Standardverfahren
zur Bestimmung der Verluste
und des Wirkungsgrades aus Prüfungen
(ausgenommen Maschinen
für Schienen- und Straßenfahrzeuge)
(IEC 60034-2-1:2007)

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CENELEC

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Foreword

The text of document 2/1443/FDIS, future edition 1 of IEC 60034-2-1, prepared by IEC TC 2, Rotating machinery, was submitted to the IEC-CENELEC parallel vote and was approved by CENELEC as EN 60034-2-1 on 2007-11-01.

This European Standard partly supersedes EN 60034-2:1996 + A1:1996 + A2:1996.

The following dates were fixed:

- latest date by which the EN has to be implemented
at national level by publication of an identical
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- latest date by which the national standards conflicting
with the EN have to be withdrawn (dow) 2010-11-01

Annex ZA has been added by CENELEC.

Endorsement notice

The text of the International Standard IEC 60034-2-1:2007 was approved by CENELEC as a European Standard without any modification.

CONTENTS

INTRODUCTION	5
1 Scope	6
2 Normative references	6
3 Terms and definitions	7
4 Symbols and abbreviated terms	12
4.1 Symbols	12
4.2 Additional subscripts	13
5 Basic requirements	14
5.1 Direct and indirect efficiency determination	14
5.2 Uncertainty	14
5.3 Preferred methods	15
5.4 Power supply	19
5.5 Instrumentation	19
5.6 Units	20
5.7 Resistance	20
6 Test methods for determination of efficiency	21
6.1 State of the machine under test and test categories	21
6.2 Excitation circuit measurements	22
6.3 Direct measurements	22
6.4 Indirect measurements	24
7 Determination of efficiency (direct current machines)	36
7.1 Determination from direct measurement	36
7.2 Determination from indirect measurement	36
8 Determination of efficiency (induction machines)	41
8.1 Determination from direct measurement	41
8.2 Determination from indirect measurement	42
9 Determination of efficiency (synchronous machines)	53
9.1 Determination from direct measurement	53
9.2 Determination from indirect measurement	54
Annex A (normative) Correction of dynamometer torque readings	60
Annex B (normative) Calculation of values for the Eh-star method	62
Annex C (informative) Types of excitation systems	65
Annex D (normative) Other test methods	66
Annex ZA (normative) Normative references to international publications with their corresponding European publications	75

Figure 1 – Sketch for torque measurement test	23
Figure 2 – Sketch for dual supply back-to-back test (for synchronous machines: $I_M = I_G, f_M = f_G$)	23
Figure 3 – Sketch for single supply back-to-back test, d.c. machines	25
Figure 4 – Sketch for single supply back-to-back test, synchronous machines	26
Figure 5 – Induction machine, T-model with equivalent iron loss resistor	30
Figure 6 – Sketch for single supply back-to-back, additional losses, d.c. machines	31
Figure 7 – Eh-star test circuit	34
Figure 8 – Vector diagram for obtaining current vector from reduced voltage test	45
Figure 9 – Induction machines, Reduced model for calculation	48
Figure 10 – Smoothing of the residual loss data	50
Figure 11 – Assigned allowance for additional load losses P_{LL} , induction machines	52
Table 1 – DC machines	16
Table 2 – Induction machines	17
Table 3 – Synchronous machines	18
Table 4 – Reference temperature	21
Table 5 – Multiplying factors for different speed ratios	41

INTRODUCTION

During the revision phase for IEC 60034-2: 1972 and its amendments IEC 60034-2 A1: 1995 (defining IEC 60034-2A: 1974 as Clause 17) and IEC 60034-2 A2: 1996, WG 28 proposed and TC 2 agreed to separate the revised standard into three sections:

- the first part (IEC 60034-2-1) to cover machines within the scope of IEC 60034-1, which are normally tested under load;
- the second part (IEC 60034-2-2) to cover tests applicable mainly for large machines where the facility cost for other methods is not economical (especially the calibrated-machine test, the retardation test and the calorimetric method);
- the third part (IEC 60034-2-3) for tests on machines for converter supply..

To retain in IEC 60034-2-1 as normative the test methods that will eventually become IEC 60034-2-2, a temporary Annex D has been added. This annex contains elements from IEC 60034-2:1972 and its amendment 1:1995. It also makes reference to IEC 60034-2A:1974. Both will be incorporated in the future IEC 60034-2-2.

ROTATING ELECTRICAL MACHINES –

Part 2-1: Standard methods for determining losses and efficiency from tests (excluding machines for traction vehicles)

1 Scope

This part of IEC 60034 is intended to establish methods of determining efficiencies from tests, and also to specify methods of obtaining specific losses.

This standard applies to d.c. machines and to a.c. synchronous and induction machines of all sizes within the scope of IEC 60034-1.

NOTE These methods may be applied to other types of machines such as rotary converters, a.c. commutator motors and single-phase induction motors.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60027-1, *Letter symbols to be used in electrical technology – Part 1: General*

IEC 60034-1, *Rotating electrical machines – Part 1: Rating and performance*

IEC 60034-2A, *Rotating electrical machines – Part 2: Methods for determining losses and efficiency of rotating electrical machinery from tests (excluding machines for traction vehicles) – First supplement: Measurement of losses by the calorimetric method*

IEC 60034-4, *Rotating electrical machines – Part 4: Methods for determining synchronous machine quantities from tests*

IEC 60034-19, *Rotating electrical machines – Part 19: Specific test methods for d.c. machines on conventional and rectifier-fed supplies*

IEC 60044 (all parts), *Instrument transformers*

IEC 60051-1, *Direct acting indicating analogue electrical measuring instruments and their accessories – Part 1: Definitions and general requirements common to all parts*

IEC 61986, *Rotating electrical machines – Equivalent loading and super-position techniques – Indirect testing to determine temperature rise*

NOTE A revision of IEC 61986 is under consideration; it will be published under reference IEC 60034-29.

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60034-1, IEC 60051-1 and the following definitions apply.

3.1

efficiency

ratio of output power to input power expressed in the same units and usually given as a percentage

3.2 Tests for direct efficiency determination

3.2.1

general

method by which the direct determination of efficiency is made by measuring directly the input power and the output power

3.2.2

torque meter test

test in which the mechanical power output of a machine acting as a motor is determined by measurement of the shaft torque by means of a torque meter together with the rotational speed. Alternatively, a test performed on a machine acting as a generator, by means of a torque meter to determine the mechanical power input

3.2.3

dynamometer test

test in accordance with 3.2.2 but measuring the shaft torque by means of a dynamometer

3.2.4

dual-supply back-to-back test

test in which two identical machines are mechanically coupled together, and the total losses of both machines are calculated from the difference between the electrical input to one machine and the electrical output of the other machine

3.3 Tests for indirect efficiency determination

3.3.1

general

test in which the indirect determination of efficiency is made by measuring the input power or the output power and determining the total losses. Those losses are added to the output power, thus giving the input power, or subtracted from the input power, thus giving the output power

3.3.2

single-supply back-to-back test

test in which two identical machines are mechanically coupled together, and are both connected electrically to the same power system. The total losses of both machines are taken as the input power drawn from the system

3.3.3

no-load test

test in which a machine run as a motor provides no useful mechanical output from the shaft, or when run as a generator with its terminals open-circuited

3.3.4**zero power factor test (synchronous machines)**

no-load test on a synchronous machine, which is over-excited and operates at a power factor very close to zero

3.3.5**equivalent circuit method (induction machines)**

test in which the losses are determined by help of an equivalent circuit model

3.3.6**test with rotor removed and reverse rotation test (induction machines)**

combined test in which the additional load losses are determined from a test with rotor removed and a test with the rotor running in reverse direction to the rotating magnetic field

3.3.7**short-circuit test (synchronous machines)**

test in which a machine is run as a generator with its terminals short-circuited

3.3.8**locked rotor test**

test in which the rotor is locked to prevent rotation

3.3.9**eh-star test**

test in which the motor is run in star connection on unbalanced voltage.

3.4 Losses**3.4.1****total losses P_T**

difference between the input power and the output power, equivalent to the sum of the constant losses (see 3.4.2), the load losses (see 3.4.4), the additional load losses (see 3.4.5) and the excitation circuit losses (see 3.4.3)

3.4.2 Constant losses**3.4.2.1****constant losses P_k**

sum of the iron losses and the friction and windage losses

3.4.2.2**iron losses P_{fe}**

losses in active iron and additional no-load losses in other metal parts

3.4.2.3 Friction and windage losses P_{fw} **3.4.2.3.1****friction losses**

losses due to friction (bearings and brushes, if not lifted at rated conditions) not including any losses in a separate lubricating system. Losses in common bearings should be stated separately, whether or not such bearings are supplied with the machine. The bearing losses are based on the operating temperatures of the bearings, the type of oil and oil temperature.

NOTE 1 When the losses in a separate lubricating system are required these should be listed separately.

For vertical machines, the losses in thrust bearings shall be determined excluding any external thrust.

NOTE 2 Additional losses due to external thrust may be stated separately by agreement, which should then include thrust load, temperature of the bearings, type of oil and also oil temperature.

NOTE 3 Friction losses due to thrust load may be included by agreement.

If the tested machine uses direct flow cooling of the bearings, these losses are distributed between the tested machine and any other one coupled to it mechanically, such as a turbine, in proportion to the masses of their rotating parts. If there is no direct flow cooling, the distribution of bearing losses shall be determined from empirical formulae by agreement

3.4.2.3.2

windage losses

total losses due to aerodynamic friction in all parts of the machine, including power absorbed in shaft mounted fans, and in auxiliary machines forming an integral part of the machine

NOTE 1 Losses in a separate ventilating system should be listed separately.

NOTE 2 For machines indirectly or directly cooled by hydrogen, see IEC 60034-1.

3.4.3 Excitation circuit losses

3.4.3.1

excitation circuit losses P_e

sum of the excitation winding losses (see 3.4.3.2), the exciter losses (see 3.4.3.3) and, for synchronous machines, electrical brush loss (see 3.4.3.5), if any

3.4.3.2

excitation winding losses P_f

the excitation (field) winding losses are equal to the product of the exciting current I_e and the excitation voltage U_e

3.4.3.3

exciter losses P_{Ed}

the exciter losses for the different excitation systems (see Annex C) are defined as follows:

a) Shaft driven exciter

The exciter losses are the power absorbed by the exciter at its shaft (reduced by friction and windage losses) plus the power P_{1E} drawn from a separate source at its excitation winding terminals, minus the useful power which the exciter provides at its terminals. The useful power at the terminals of the exciter is equal to the excitation winding losses as per 3.4.3.2 plus (in the case of a synchronous machine) the electrical brush losses as per 3.4.3.5.

If the exciter can be decoupled and tested separately its losses can be determined according to 5.3.

Whenever the exciter makes use of separate auxiliary supplies, their consumptions are to be included in the exciter losses unless they are considered together with the main machine auxiliaries consumption.

b) Brushless exciter

The exciter losses are the power absorbed by the exciter at its shaft, reduced by friction and windage losses (when the relevant test is performed on the set of main machine and exciter), plus the electrical power P_{1E} from a separate source (if any) absorbed by its field winding or its stator winding (in the case of an induction exciter), minus the useful power which the exciter provides at the rotating power converter terminals.

Whenever the exciter makes use of separate auxiliary supplies their consumptions are to be included in the exciter losses unless they are considered together with the main machine auxiliaries consumption.

If the exciter can be decoupled and tested separately, its losses can be determined according to 5.3.

c) Separate rotating exciter

The exciter losses are the difference between the power absorbed by the driving motor, plus the power absorbed by separate auxiliary supplies, of both driving and driven machines, including the power supplied by separate source to their excitation winding terminals, and the excitation power supplied as per 3.4.3.2 and 3.4.3.4. The exciter losses may be determined according to 5.3.

d) Static excitation system (static exciter)

The excitation system losses are the difference between the electrical power drawn from its power source, plus the power absorbed by separate auxiliary supplies, and the excitation supplied as per 3.4.3.2 and 3.4.3.4.

In the case of systems fed by transformers, the transformer losses shall be included in the exciter losses.

e) Excitation from auxiliary winding (auxiliary winding exciter)

The exciter losses are the copper losses in the auxiliary (secondary) winding and the additional iron losses produced by increased flux harmonics. The additional iron losses are the difference between the losses which occur when the auxiliary winding is loaded and when it is unloaded.

Because separation of the excitation component of losses is difficult, it is recommended to consider these losses as an integral part of the stator losses when determining overall losses.

In the cases c) and d) no allowance is made for the losses in the excitation source (if any) or in the connections between the source and the brushes (synchronous machine) or between the source and the excitation winding terminals (d.c. machine).

If the excitation is supplied by a system having components as described in b) to e) the exciter losses shall include the relevant losses of the components pertaining to the categories listed in Annex C as applicable.

3.4.3.4**separately supplied excitation power P_{1E}**

the excitation power P_{1E} supplied from a separate power source is:

- for exciter types a) and b) the exciter excitation power (d.c. or synchronous exciter) or stator winding input power (induction exciter). It covers a part of the exciter losses P_{Ed} (and further losses in induction exciters) while a larger part of P_e is supplied via the shaft;

- for exciter types c) and d) equal to the excitation circuit losses, $P_{1E} = P_e$;
- for exciter type e) $P_{1E} = 0$, the excitation power being delivered entirely by the shaft. Also, $P_{1E} = 0$ for machines with permanent magnet excitation.

Exciter types shall be in accordance with 3.4.3.3

3.4.3.5

brush losses P_b (excitation circuit)

electrical brush loss (including contact loss) of separately excited synchronous machines

3.4.4 Load losses

3.4.4.1

load losses P_L

the sum of the winding (I^2R) losses (see 3.4.4.2) and the electrical brush losses (see 3.4.4.3), if any

3.4.4.2

winding losses

winding losses are I^2R losses:

- in the armature circuit of d.c. machines;
- in the stator and rotor windings of induction machines;
- in the armature windings of synchronous machines

3.4.4.3

brush losses P_b (load circuits)

electrical brush loss (including contact loss) in the armature circuit of d.c. machines and in wound-rotor induction machines

3.4.5

additional load losses P_{LL} (stray-load losses)

losses produced by the load current in active iron and other metal parts other than conductors; eddy current losses in winding conductors caused by load current-dependent flux pulsations and additional brush losses caused by commutation

NOTE These losses do not include the additional no-load losses of 3.4.2.2.

3.4.6

short-circuit losses P_{sc}

current-dependent losses in a synchronous machine and in a d.c. machine when the armature winding is short-circuited

3.5 Test quantities (polyphase a.c. machines)

3.5.1

terminal voltage

for polyphase a.c. machines the arithmetic average of line voltages

3.5.2

line current

for polyphase a.c. machines the arithmetic average of line currents

3.5.3**line-to-line resistance**

for polyphase a.c. machines, the arithmetic average of line-to-line resistance across each set of terminals

NOTE 1 For Y-connected three-phase machines, the phase-resistance is 0,5 line-to-line resistance. For Δ -connected machines, the phase-resistance is 1,5 line-to-line resistance.

NOTE 2 In Clauses 7, 8 and 9, explanations and equations given are for three-phase machines, unless otherwise indicated.

4 Symbols and abbreviated terms**4.1 Symbols**

$\cos \varphi$	is the power factor ¹
f	is the supply frequency, Hz
I	is the average line current, A
k_{θ}	is the temperature correction factor
n	is the operating speed, s ⁻¹
p	is the number of pole pairs
P	is the power, W
P_0	is the input power at no-load, W
P_1	is the input power, excluding excitation ² , W
P_2	is the output power, W
P_b	is the brush loss, W
P_e	is the excitation circuit losses, W
P_{1E}	is the excitation power supplied by a separate source, W
P_{Ed}	is the exciter losses, W
P_{el}	is the electrical power, excluding excitation, W
P_f	is the excitation (field) winding losses, W
P_{fe}	is the iron losses, W
P_{fw}	is the friction and windage losses, W
P_C	is the constant losses, W
P_L	is the load losses, W
P_{Lr}	is the residual losses, W
P_{LL}	is the additional-load losses, W
P_{mech}	is the mechanical power, W
P_k	is the short-circuit losses, W
P_T	is the total losses, W
P_w	is the winding losses, W, where subscript w is generally replaced by a, f, e, s or r

¹ This definition assumes sinusoidal voltage and current.

² Unless otherwise indicated, the tests in this document are described for motor operation, where P_1 and P_2 are electrical input and mechanical output power, respectively.

R	is a winding resistance, Ω
R_{eh}	is the actual value of the auxiliary resistor used for the Eh-star test (see 6.4.5.5), Ω
R'_{eh}	is the typical value of the auxiliary resistor, Ω
R_f	is the field winding resistance, Ω
R_{ll}	is the average line-to-line-resistance, Ω
R_{ph}	is the average phase-resistance, Ω
s	is the slip, in per unit value of synchronous speed
T	is the machine torque, N·m
T_d	is the reading of the torque measuring device, N·m
T_c	is the torque correction, N·m
U	is the average terminal voltage, V
U_0	is the terminal voltage at no-load, V
U_N	is the rated terminal voltage, V
X	is the reactance, Ω
$\underline{Z} = R + j \times X$	is the notation for a complex quantity (impedance as example)
$Z = \underline{Z} = \sqrt{R^2 + X^2}$	is the absolute value of a complex quantity (impedance as example)
Z	is the impedance, Ω
η	is the efficiency
θ_0	is the initial winding temperature, °C
θ_a	is the ambient temperature, °C
θ_c	primary coolant inlet temperature, °C
θ_w	is the winding temperature, °C
τ	is a time constant, s

4.2 Additional subscripts

The following subscripts may be added to symbols to clarify the machine function and to differentiate values.

Machine components:

a	armature
e	excitation
f	field winding
r	rotor
s	stator
w	winding
U, V, W	phase designations

Machine categories:

B	booster
D	dynamometer
E	exciter
G	generator
M	motor

Operating conditions:

0	no-load
1	input
2	output
av	average, mean
d	dissipated
el	electrical
i	internal
L	test load
lr	locked rotor
mech	mechanical
N	rated
red	at reduced voltage
t	test
zpf	zero power factor test
θ	corrected to a reference coolant temperature.

NOTE Further additional subscripts are introduced in relevant subclauses.

5 Basic requirements

5.1 Direct and indirect efficiency determination

Tests can be grouped into the three following categories:

- input-output measurement on a single machine. This involves the measurement of electrical or mechanical power into, and mechanical or electrical power out of a machine;
- input and output measurement on two identical machines mechanically connected back-to-back. This is done to eliminate the measurement of mechanical power into or out of the machine;
- measurement of the actual loss in a machine under a particular condition. This is not usually the total loss but comprises certain loss components. The method may, however, be used to calculate the total loss or to calculate a loss component.

The determination of total losses shall be carried out by one of the following methods:

- measurement of total losses;
- determination of separate losses for summation;

NOTE The methods for determining the efficiency of machines are based on a number of assumptions. Therefore, it is not possible to make a comparison between the values of efficiency obtained by different methods.

5.2 Uncertainty

Uncertainty as used in this standard is the uncertainty of determining a true efficiency. It reflects variations in the test procedure and the test equipment.

Although uncertainty should be expressed as a numerical value, such a requirement needs sufficient testing to determine representative and comparative values. This standard uses the following relative uncertainty terms:

- "low" applies to efficiency determinations based solely upon test results;
- "medium" applies to efficiency determinations based upon limited approximations;
- "high" applies to efficiency determinations based upon assumptions.

5.3 Preferred methods

It is difficult to establish specific rules for the determination of efficiency. The choice of test to be made depends on the information required, the accuracy required, the type and size of the machine involved and the available field test equipment (supply, load or driving machine).

Preferred methods are given for each machine configuration in Tables 1 to 3. The test method should be selected from the procedures with the lowest uncertainty.

Table 1 – DC machines

Method	Clause	Preferred method	Required facilities	Uncertainty
Direct				
Calibrated machine test	Annex D		Calibrated machine	See Note 3
Torque measurement	7.1.1	Machine size: $H \leq 180$	Torquemeter/dynamometer for full-load	Low
Total losses				
Single-supply, back-to-back test	7.2.1.1		Two identical units Booster generator	Low
Summation of losses, with load test				
P_{LL} d.c. component: single supply back-to-back test	7.2.2.6.1		Two identical units Booster generator	Low
P_{LL} d.c. component from assigned value	7.2.2.6.3			Medium
P_{LL} a.c. component from specified rectifier supply	7.2.2.6.2	Machine size: $H > 180$	Specified rectifier	Low
Summation of losses, without load test				
Excitation loss from an assigned ratio of load to no- load excitation current P_{LL} from assigned value	7.2.2.5		If test equipment for other tests is not available (no possibility of loading, no duplicate machine)	High
NOTE 1 Due to instrumentation inaccuracies the direct test method is limited to efficiencies up to 95 % to 96 %. For practical purposes, this standard recommends direct tests for machines up to shaft height 180 mm since these are not likely to exceed 95 % efficiency. Machines of larger size and efficiencies below 95 % to 96 % may also be tested successfully using the direct test method. NOTE 2 In the "Uncertainty" column, "Low" indicates a procedure determining all loss-components from tests; "Medium" indicates a procedure which is based on a simplified physical model of the machine; "High" indicates a procedure that does not determine all loss-components by tests. NOTE 3 Uncertainty to be determined.				

Table 2 – Induction machines

Method	Clause	Preferred method	Required facilities	Uncertainty
Direct				
Torque measurement	8.1.1	All single phase and polyphase ≤ 1 kW	Torquemeter/dynamometer for full-load	Low
Calibrated machine test	Annex D		Calibrated machine	See Note 4
Dual-supply, back-to-back test	8.1.2		Machine set for full-load Two identical units	Low
Total losses				
Calorimetric method	Annex D		Special thermal enclosure	See Note 4
Single supply back-to-back test	8.2.1		Two identical units (wound rotor)	Low
Summation of losses, with and without load test				
P_{LL} determined from residual loss	8.2.2.5.1	Three phase > 1 kW up to 150 kW	Torquemeter/dynamometer for $\geq 1,25 \times$ full-load	Low
P_{LL} from assigned value	8.2.2.5.3			Medium to high
P_{LL} from removed rotor and reverse rotation test	8.2.2.5.2		Auxiliary motor with rated power $\leq 5 \times$ total losses P_T	High
P_{LL} from Eh-star test	8.2.2.5.4	(see Note 3)	Resistor for 150 % rated phase current	Medium
Summation of losses, without load test				
Currents, powers and slip from the equivalent circuit method P_{LL} from assigned value	8.2.2.4.3		If test equipment for other tests is not available (no possibility of applying rated load, no duplicate machine)	Medium/high
NOTE 1 Due to measurement inaccuracies, the determination of P_{LL} from residual losses is limited to correlation coefficients (see 8.2.2.5.1.2) greater than 0,95 and may have uncertainties of the determined efficiency exceeding $\pm 0,5$ %. NOTE 2 In the "Uncertainty" column, "Low" indicates a procedure determining all loss-components from tests; "Medium" indicates a procedure which is based on a simplified physical model of the machine; "High" indicates a procedure that does not determine all loss-components by tests. NOTE 3 The method for P_{LL} from Eh-star test is suitable for motors between 1 kW and 150 kW; larger ratings are under consideration. The method requires that the winding can be connected in star. NOTE 4 Uncertainty to be determined.				

Table 3 – Synchronous machines

Method	Clause	Preferred method	Required facilities	Uncertainty
Direct				
Torque measurement	9.1.1	Machine size: $H \leq 180$	Torquemeter/dynamometer for full-load	Low
Calibrated machine test	Annex D		Calibrated machine	See Note 3
Dual-supply, back-to-back test	9.1.2		Two identical units	Medium
Total losses				
Zero power factor with excitation current from Potier/ASA/Swedish diagram	9.2.1.2		Supply for full voltage and current	Medium
Calorimetric method	Annex D		Special thermal enclosure	See Note 3
Single supply back-to-back test	9.2.1.1		Two identical units	Low
Summation of losses, with load test				
Summation except P_{LL}	9.2.1		Machine set for full-load	High
P_{LL} from short-circuit test	9.2.2.6	Machine size $H > 180$		Low
Summation of losses, without load test				
Excitation current from Potier/ASA/Swedish diagram P_{LL} from short-circuit test	9.2.2.4 9.2.2.6		If test equipment for other tests is not available (no possibility of applying rated load, no duplicate machine)	Medium
NOTE 1 Due to instrumentation inaccuracies, the direct test method is limited to efficiencies up to 95 % to 96 %. For practical purposes, this standard recommends direct tests for machines up to shaft heights of 180 mm since these are not likely to exceed 95 % efficiency. Machines of larger size and efficiencies below 95 % to 96 % may also be tested successfully using the direct test method. NOTE 2 In the "Uncertainty" column, "Low" indicates a procedure determining all loss-components from tests; "Medium" indicates a procedure which is based on a simplified physical model of the machine; "High" indicates a procedure that does not determine all loss-components by tests. NOTE 3 Uncertainty to be determined.				

NOTE In the tables, H is the shaft height (distance from the centre line of the shaft to the bottom of the feet), in millimetres (see frame numbers in IEC 60072-1).

5.4 Power supply

5.4.1 Voltage

The voltage shall be in accordance with 7.2 (and 8.3.1 for thermal tests) of IEC 60034-1.

5.4.2 Frequency

The frequency shall be within $\pm 0,3$ % of the rated frequency during measurements.

NOTE This requirement does not apply for the equivalent-circuit method (6.4.4.4).

5.5 Instrumentation

5.5.1 General

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

NOTE For analog instruments the observed values should be in the upper third of the instrument range.

5.5.2 Measuring instruments for electrical quantities

The measuring instruments shall have an accuracy class of 0,2 in accordance with IEC 60051.

NOTE For a routine test as described in 9.1 of IEC 60034-1, an accuracy class of 0,5 is sufficient.

Unless otherwise stated in this standard, the arithmetic average of the three line currents and voltages shall be used.

5.5.3 Instrument transformers

Instrument transformers shall have an accuracy according to IEC 60044-1 so that the errors of the instrument transformers are not greater than $\pm 0,5$ % for general testing or not greater than $\pm 0,3$ % for induction machines, summation of losses method, with additional load loss determination in accordance with 8.2.2.5.1.

5.5.4 Torque measurement

The instrumentation used to measure the torque shall have an accuracy of $\pm 0,2$ % of full scale.

When the shaft torque is measured by means of a dynamometer, a torque correction test shall be carried out. This also applies if any bearing or coupling is interposed between the torque measuring device and the motor shaft. The machine torque T is calculated using the equation:

$$T = T_d + T_c$$

where

T_d is the torque reading of the load test;

T_c is the torque correction according to Annex A.

5.5.5 Speed and frequency measurement

The instrumentation used to measure frequency shall have an accuracy of $\pm 0,1$ % of full scale. The speed measurement should be accurate within 0,1 % or 1 revolution per minute whichever gives the least error.

NOTE 1 Speed in min^{-1} is n in $\text{s}^{-1} \times 60$.

NOTE 2 The measurement of slip by a suitable method should replace speed measurement.

5.5.6 Temperature measurement

The instrumentation used to measure winding temperature shall have an accuracy of ± 1 °C.

5.6 Units

Unless otherwise specified, the units of values are SI-units as listed in IEC 60027-1.

5.7 Resistance

5.7.1 Test resistance

Winding resistance R is the ohmic value, determined by appropriate methods.

For d.c. machines, R is the total resistance of all windings carrying armature current (armature, commutating, compensating winding, compound winding). Where resistance measurement is impracticable due to very low resistances, calculated values are permissible.

For d.c. and synchronous machines, R_f is the field winding resistance.

For polyphase a.c. machines, $R = R_{ll}$ is the line-to-line resistance of the stator or armature winding according to 3.5.3. In the case of wound rotor induction machines, $R_{r, ll}$ is the rotor line-to-line resistance. The test resistance at the end of the thermal test shall be determined similar to the extrapolation procedure as described in 8.6.2.3.3 of IEC 60034-1, using the shortest possible time instead of the time interval specified in Table 5 therein, and extrapolating to zero.

The test temperature of windings shall be determined according to 5.7.2.

When winding resistance (under load) cannot be measured directly, the test resistance value shall be adjusted by the difference between the temperature of measured resistance and the temperature derived according to 5.7.2, methods a) to e).

5.7.2 Winding temperature

The winding test temperature shall be determined by one of the following methods (shown in order of preference):

- temperature determined from the rated load test resistance R_N by the extrapolation procedure as described in 5.7.1;
- temperature measured directly by either ETD or thermocouple;
- temperature determined according to a) on a duplicate machine of the same construction and electrical design;
- when load capability is not available, determine operating temperature according to IEC 61986;

- e) when the rated load test resistance R_N cannot be measured directly, the winding temperature shall be assumed equal to the reference temperature of the rated thermal class as given in Table 4.

Table 4 – Reference temperature

Thermal class of the insulation system	Reference temperature °C
130 (B)	95
155 (F)	115
180 (H)	135

If the rated temperature rise or the rated temperature is specified as that of a lower thermal class than that used in the construction, the reference temperature shall be that of the lower thermal class.

5.7.3 Correction to reference coolant temperature

The winding resistance values recorded during test shall be referred to a standard reference temperature of 25 °C. The correction factor to adjust the winding resistance (and the slip in the case of cage induction machines) to a standard reference coolant temperature of 25 °C shall be determined by

$$k_{\theta} = \frac{235 + \theta_w + 25 - \theta_c}{235 + \theta_w}$$

where

k_{θ} is the temperature correction factor for windings;

θ_c is the inlet coolant temperature during test;

θ_w is the winding temperature according to 5.7.2.

The temperature constant 235 is for copper; this should be replaced by 225 for an aluminium winding.

For machines with water as the primary or secondary coolant, the water reference temperature shall be 25 °C according to Table 4 of IEC 60034-1. Alternative values may be specified by agreement.

6 Test methods for determination of efficiency

6.1 State of the machine under test and test categories

Tests shall be conducted on an assembled machine with the essential components in place, to obtain test conditions equal or very similar to normal operating conditions.

NOTE It is preferable that the machine be selected randomly from series production without special considerations.

NOTE Sealing elements may be removed during the tests, if an additional test on machines of similar design has shown that friction is insignificant after adequately long operation.

The sub-tests that make up a test procedure shall be performed in the sequence listed. It is not essential that the tests be carried out immediately one after another. However, if the sub-tests are performed with delay or individually, then the specified thermal conditions shall be re-established prior to obtaining the test data.

On machines with adjustable brushes, the brushes shall be placed in the position corresponding to the specified rating. On induction motors with wound rotor having a brush lifting device, the brushes shall be lifted during tests, with the rotor winding short-circuited. For measurements on no-load, the brushes shall be placed in the neutral axis on d.c. machines.

6.2 Excitation circuit measurements

Determination of voltage U_e and current I_e (see 3.4.3.2) depends on the configurations of the excitation system (see 3.4.3.3). Where applicable, test data shall be recorded according to the following:

- a) for machines excited by shaft driven, separate rotating, static and auxiliary winding exciters (see 3.4.3.3 a), c), d) and e)), voltage U_e and current I_e are measured:
 - at the excitation winding terminals of d.c. machines;
 - at the field winding slip-rings of synchronous machines;
- b) for machines excited by brushless exciters (see 3.4.3.3 b)), test data shall be recorded by either of the following methods:
 - voltage U_e measured using auxiliary (provisional) slip-rings connected to the field winding ends. From the voltage and resistance R_e determine the field winding current $I_e = \frac{U_e}{R_e} = \frac{U_f}{R_f}$. The field winding resistance is to be measured after switching off the machine using the extrapolation procedure according to 5.7.1;
 - voltage U_e and current I_e measured using power slip-rings suitable for direct measurement of field winding current.

NOTE The difference between U_e and U_f (voltage drop) is in practice almost negligible.

Voltages and currents shall be measured at stabilized temperatures.

The excitation circuit losses P_e are determined according to 7.2.2.5 (d.c. machines) or 9.2.2.4 (synchronous machines).

6.3 Direct measurements

6.3.1 Torque measurement tests

6.3.1.1 General

These are test methods in which the mechanical power P_{mech} of a machine is determined by measurement of the shaft torque and speed. The electrical power P_{el} (of the stator in a.c. machines, of the armature in d.c. machines) is measured in the same test.

Input and output power are:

- in motor operation: $P_1 = P_{\text{el}}; P_2 = P_{\text{mech}}$ (see Figure 1);
- in generator operation: $P_1 = P_{\text{mech}}; P_2 = P_{\text{el}}$

NOTE It is generally advisable to take several readings of all instruments at each load-point in short periods of time and average the results to obtain a more accurate test value.