

INTERNATIONAL STANDARD

NORME INTERNATIONALE

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

**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)**



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Withholding

INTERNATIONAL ELECTROTECHNICAL COMMISSION

ROTATING ELECTRICAL MACHINES –

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

FOREWORD

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International Standard IEC 60034-2-1 has been prepared by IEC technical committee 2: Rotating machinery.

This standard cancels and replaces IEC 60034-2 (1972), its amendment 1 (1995) and its amendment 2 (1996). IEC 60034-2A (1974) is retained for the time being.

The text of this standard is based on the following documents:

FDIS	Report on voting
2/1443/FDIS	2/1460/RVD

Full information on the voting for the approval of this standard can be found in the report on voting indicated in the above table.

A list of all parts of IEC 60034 series, under the general title *Rotating electrical machines*, can be found on the IEC website.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

The committee has decided that the contents of this publication will remain unchanged until the maintenance result date indicated on the IEC web site under "<http://webstore.iec.ch>" in the data related to the specific publication. At this date, the publication will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

Withdrawn

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.

Withdrawn

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, $^{\circ}\text{C}$
θ_a	is the ambient temperature, $^{\circ}\text{C}$
θ_c	primary coolant inlet temperature, $^{\circ}\text{C}$
θ_w	is the winding temperature, $^{\circ}\text{C}$
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.

Withdrawn

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

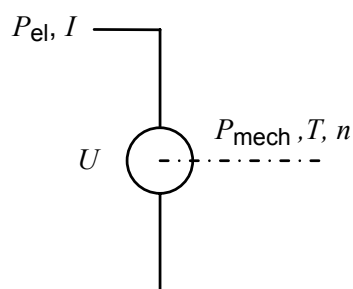
6.3.1.1 General

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.



IEC 1301/07

Figure 1 – Sketch for torque measurement test

6.3.1.2 Torquemeter test

Couple either the motor under test to a load machine or the generator under test to a motor with a torque meter. Operate the machine under test at the required load.

Record $U, I, P_{el}, n, T, \theta_c$.

When excitation is required, proceed according to 6.2.

6.3.1.3 Dynamometer test

Couple the test machine to a dynamometer. Calibrate the dynamometer so that the dynamometer reading is 0,0 when the shaft torque is 0,0 (see 5.5.3). Operate the machine at the required load.

Record $U, I, P_{el}, n, T, \theta_c$.

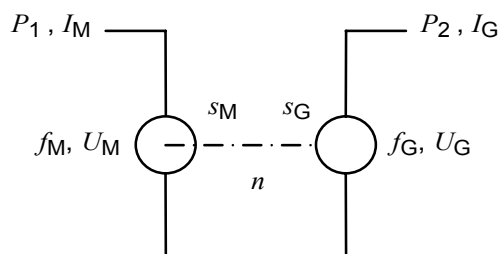
When excitation is required, proceed according to 6.2.

6.3.2 Dual-supply back-to-back test

6.3.2.1 General

Mechanically, couple two identical machines together (see Figure 2).

Tests are made with the power supplies exchanged but with the instruments and instrument transformers remaining with the same machine.



IEC 1302/07

Figure 2 – Sketch for dual supply back-to-back test
(for synchronous machines: $I_M = I_G, f_M = f_G$)

6.3.2.2 Induction machines

Connect the driven machine (induction generator) terminals to either a machine set or a converter with low harmonic distortion, supplying reactive power and absorbing active power. Supply one machine (the motor for motor rating, the generator for generator rating) with rated voltage and frequency; the second one shall be supplied with a frequency lower than that of the first machine for generator operation or higher for motor operation. The voltage of the second machine shall be that required to result in the rated voltage-to-frequency ratio.

Reverse the motor and generator connections and repeat the test.

For each test, record:

- U_M, I_M, P_1, f_M, s_M for the motor;
- U_G, I_G, P_2, f_G, s_G for the generator;
- θ_c .

6.3.2.3 Synchronous machines

The voltage and current of the two machines shall be identical, and one machine (the motor for motor rating, the generator for generator rating) shall have a rated power factor. This can be achieved by a set of synchronous and d.c. machines feeding the generator output back to the line.

NOTE Power factor and excitation current of the other machine will deviate from rated values because of the losses absorbed by the two machines.

Reverse the motor and generator connections and repeat the test.

For each test, record: $U, I, f, P_1, P_2, \cos \phi_M, \cos \phi_G, \theta_c$.

For excitation systems proceed according to 6.2.

6.4 Indirect measurements

6.4.1 Total losses

6.4.1.1 Single-supply, back-to-back test

6.4.1.1.1 General

This test is applicable to d.c. wound-rotor induction and synchronous machines. Mechanically couple two identical machines together and connect them both electrically to the same power supply so as to operate at rated speed and rated voltage, one as a motor and the other as a generator.

NOTE Alternatively, the losses can be supplied either by a calibrated driving motor, a booster, or otherwise by a combination of these various means.

6.4.1.1.2 DC machines

Connect the driven machine to the supply with a booster generator in series (see Figure 3). Operate both machines at approximately the current and the internal voltage corresponding to the load point for which the efficiency is required. For motors, the supply shall deliver rated voltage and the required load to the motor. For generators, the voltage has to be adjusted by the booster for rated voltage and the required load at the generator. The voltage supply mainly covers the no-load losses, the booster covers the load losses.

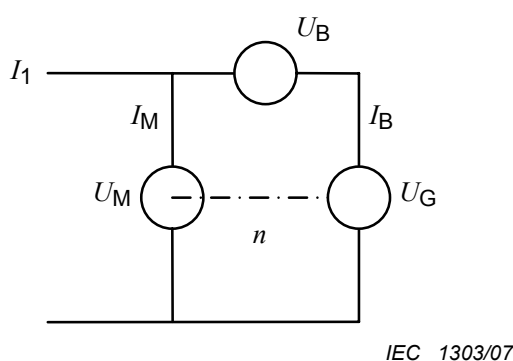


Figure 3 – Sketch for single supply back-to-back test, d.c. machines

If no booster is available, the common terminal voltage should be adjusted so that the mean value of the currents of both machines is the rated current.

For each test, record:

- U_M , I_1 of the power supply;
- P_M absorbed at the motor terminals;
- U_B , I_B of the booster;
- n , θ_c .

For excitation systems, proceed according to 6.2.

6.4.1.1.3 Induction machines with wound rotor

The rotor winding of the motor shall be short-circuited and the rotor winding of the generator shall be connected to a polyphase supply suitable to deliver rated rotor current at slip-frequency. The desired motor-power will be achieved by adjusting frequency and current of the lower frequency power supply.

For each test, record:

- U_1 , P_1 , I_1 of the power-frequency supply;
- U_r , I_r , P_r of the low-frequency supply,
- P_M absorbed at the motor terminals;
- P_G delivered by the generator;
- θ_c .

6.4.1.1.4 Synchronous machines

Mechanically couple the machines with an angular displacement of their rotors enabling one machine to operate at the load conditions for which the efficiency is required, and the other machine to operate at the same absolute value of stator current (see Figure 4).

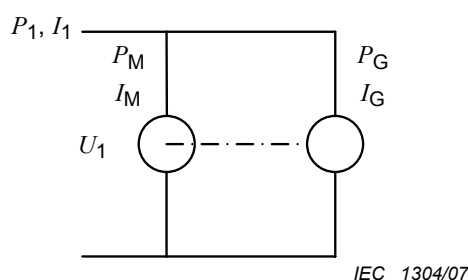


Figure 4 – Sketch for single supply back-to-back test, synchronous machines

NOTE The displacement expressed as electrical angle α for this condition is approximately the double internal electrical angle at the required load condition. In general, for a given voltage the circulating power depends on the angle α and on the excitation currents of the motor and generator. Adjust the current and power factor to rated values at one machine; the deviation in excitation current from the rated value at the other machine can be used for accuracy considerations.

For each test, record:

- U_1, I_1, P_1 of the power-frequency supply;
- I_M, P_M of the motor;
- I_G, P_G of the generator;
- excitation system values according to 6.2;
- θ_c .

6.4.1.2 Zero power factor test (synchronous machines)

Prior to this test, the results of a no-load saturation test, a sustained polyphase short-circuit test and an over-excitation test at zero power factor, in accordance with Clauses 25, 26 and 28 of IEC 60034-4, shall be available.

Operate the machine uncoupled as a motor, at rated speed and over-excited. Adjust the supply voltage to the same electromotive force E and armature current I (at a power factor near zero) as at the desired load.

NOTE 1 E is the vectorial sum of terminal voltage and Potier reactance voltage drop according to Clauses 30 and 31 of IEC 60034-4.

The test shall be made as near as possible to the stabilized operating temperature attained in operation at rated load and at the end of the time specified in the rating. No winding temperature correction shall be made.

NOTE 2 For the above test, it is necessary that the supply voltage is adjustable so that the iron losses have the same value during this test as at a rated power factor under load at rated voltage. If the supply voltage is not adjustable but is equal to the rated voltage, this could give an active iron loss appreciably different from that at full-load. In principle, reactive power should be delivered (i.e. machine over-excited), but when this is impossible due to limited exciter voltage, the test may be made with reactive power absorbed (i.e. machine under-excited) as far as stable running is possible.

The excitation winding losses at the desired load will be obtained from the excitation current estimated according to Clause 31 of IEC 60034-4 (Potier diagram), or Clause 32 (ASA diagram), or Clause 33 (Swedish diagram). For the determination of exciter losses see 6.4.3.3. When E of the zero power-factor test deviates from that at the desired load, the iron loss difference shall be obtained from the iron loss curve (see 6.4.2.3) and the two voltage values of E .

NOTE 3 The accuracy of this method depends on the accuracy of the wattmeters and the instrument transformers at low power factor.

Record at zero power factor:

- U, f, I, P_1 ;
- excitation system values according to 6.2;
- θ_c and θ_w .

6.4.2 Constant losses

6.4.2.1 General

In the case of d.c. or synchronous machines, the machine can be tested running as an uncoupled motor or coupled with a driving machine and operating as a generator (supplied power from torque, measured according to 6.3.1.2 or 6.3.1.3).

6.4.2.2 Conditions for no-load test

The no-load losses shall be stabilized according to the following conditions:

- rated speed and voltage for a d.c. machine (by adjusting the field current);
- rated frequency and voltage for an induction machine;
- rated frequency and voltage for a synchronous machine (by adjusting the excitation current), and unity power factor (minimum current) when running as an uncoupled motor.

NOTE 1 In the case of a d.c. or synchronous machine with shaft driven exciter (see 3.4.3.3 a)), the machine should be separately excited and the exciter disconnected from its supply and from the excitation winding.

The no-load losses are considered stabilized when the no-load power input varies by 3 % or less, when measured at two successive 30 min intervals.

NOTE 2 The no-load losses are also considered stabilized if the no-load test is carried out immediately after the load-test.

6.4.2.3 Friction and windage losses, iron loss

Test at a minimum number of seven values of voltage, including rated voltage, so that:

- four or more values are read approximately equally spaced between 125 % and 60 % of rated voltage;
- three or more values are read approximately equally spaced between 50 % and approximately 20 % of rated voltage, or (for an uncoupled running machine) to a point where the current no longer decreases.

For uncoupled d.c. machines, the speed shall be maintained constant by adjusting the field current.

The test shall be carried out as quickly as possible with the readings taken in descending order of voltage.

Record at each of the voltage values: U_0 , I_0 , P_0 , R_0 .

where

R_0 is determined by measuring the resistance after the lowest voltage readings.

NOTE 1 For a.c. machines R_0 is $R_{ll,0}$, and for d.c. machines, R_0 is the total resistance of all windings carrying armature current (armature, commutating, compensating winding). Where resistance measurement is impracticable due to very low resistances, calculated values are permissible.

For a coupled machine, P_0 is determined from T and n .

Record excitation system values according to 6.2.

NOTE 2 For large synchronous machines it is recommended to record other values influencing efficiency, for example coolant temperature, gas purity, gas pressure, sliding bearings oil temperature, bearing oil viscosity.

6.4.3 Excitation circuit losses

6.4.3.1 Determination from a load test

Operate the machine at rated load as described in 6.4.4.1 until temperatures have stabilized.

Record excitation system values according to 6.2.

6.4.3.2 Determination without load test

In the case of a synchronous machine, the excitation current I_e shall be determined according to Clause 31 of IEC 60034-4 (Potier diagram), or Clause 32 (ASA diagram), or Clause 33 (Swedish diagram) from a no-load test, a short-circuit test and a zero power factor test, or an armature reactance test without rotor.

Record I_e for each load point.

NOTE In the case of machines for which the above tests cannot be performed, the excitation current value provided by the manufacturer should be used to calculate the winding loss.

6.4.3.3 Exciter losses

Uncouple the exciter from the main machine (if possible), then couple the exciter to:

- a) a torque measuring device to determine the mechanical power input according to 6.3.1;
or
- b) a calibrated driving motor to measure the motor electrical power input.

Connect the exciter (in the case of a synchronous machine excited via slip-rings) to a suitable resistive load. Operate the exciter unexcited and with voltage U_e and current I_e for each of the load points.

Record:

- U_e , I_e , P_{Ed} , n , T_E for each load point (P_{Ed} according to 3.4.3.3);
- $T_{E,0}$ (the torque with the exciter unexcited).

NOTE Alternatively, the exciter may be coupled to a calibrated motor, the electrical input power of which is recorded.

When the exciter cannot be uncoupled from the machine, the exciter losses shall be provided by the manufacturer.

6.4.4 Load losses

6.4.4.1 Rated load temperature test

The machine shall be loaded by suitable means, with supply power according to the machine rating and operated until thermal equilibrium is achieved (gradient of 2 K per hour).

At the end of the rated-load test, record:

- P_N , I_N , U_N , s , f , θ_C , θ_N ;
- $R_N = R$ (the test resistance for rated load according to 5.7.1);
- θ_N (the winding temperature at rated load according to 5.7.2).

In the case of d.c. machines on rectified power, the mean value I_{av} and the r.m.s. value I shall be measured.

NOTE 1 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.

NOTE 2 For d.c. machines, $f = 0$.

For values to be measured to get excitation winding losses and additional losses from a load test see 6.4.3.1 and 6.4.5.3.

6.4.4.2 Load curve test

NOTE 1 This test is primarily applicable for the determination of additional losses in induction motors.

Prior to the start of recording data for this test, the temperature of the windings shall be within 5 K of the temperature θ_N , obtained from a rated load temperature test (see 6.4.4.1).

The machine shall be loaded by suitable means.

Apply the load to the machine at six load points. Four load points should be chosen to be approximately equally spaced between not less than 25 % and up to and including 100 % load. The remaining two approximately equally-spaced load points should be suitably chosen above 100 % load, but not exceeding 150 % load. When loading the machine, start at the highest load value and proceed in descending order to the lowest. These tests shall be performed as quickly as possible to minimize temperature changes in the machine during testing.

In a.c. machines, frequency variation between all points shall be less than 0,1 %. Measure R before the highest and after the lowest load reading. The resistance for 100 % load and higher loads shall be the value determined before the highest load reading. The resistance used for loads less than 100 % shall then be determined as linear with load, using the reading before the test for the highest load and after the lowest reading for 25 % load.

NOTE 2 In a.c. machines, resistances may also be determined by measuring the stator winding temperature using a temperature-sensing device installed on the winding. Resistances for each load point may then be determined from the temperature of the winding at that point in relation to the resistance and temperature measured before the start of the test.

Record for each load point: U, I, P_1, R, n, f, T

where R is according to 5.7.1.

6.4.4.3 Load test at reduced voltage (induction machines)

This is an appropriate method for large machines which cannot be tested at full load. The following are required: a load test with the machine acting as a motor at rated speed, a no-load test at reduced voltage U_{red} , and a no-load test at rated voltage and rated frequency.

Using this method, it is assumed that at reduced voltage, while keeping the speed constant, currents diminish as the voltage and power diminishes as the square of the voltage.

At reduced voltage, record: $U_{red}, I_{red}, P_{1red}, I_{0red}, \cos(\varphi_{0red})$.

At rated voltage, record: $U_N, I_0, \cos(\varphi_0)$.

6.4.4.4 Equivalent circuit method (induction machines)

6.4.4.4.1 General

This method may be applied when a load test is not possible. It is based on the conventional T-model per-phase circuit of an induction machine, including an equivalent iron-loss resistor parallel to the main field reactance (see Figure 5). The rotor side parameters and quantities are referred to the stator side; this is indicated by the presence of an apostrophe ' at the symbols for example $X'_{\sigma r}$.

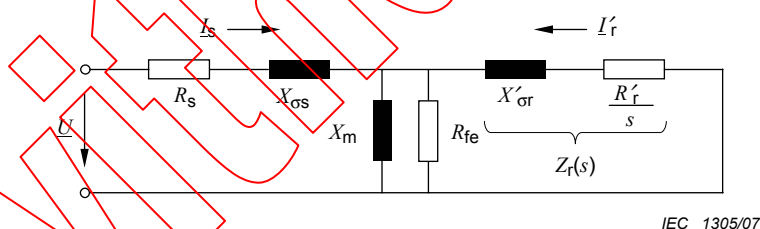


Figure 5 – Induction machine, T-model with equivalent iron loss resistor

Application of the method to cage induction machines requires the following designed values to be available.

- $\frac{X_{\sigma s}}{X'_{\sigma r}}$ ratio of stator leakage to stator referred rotor leakage reactance.
- α_r temperature coefficient of the rotor windings (conductivity referred to 0 °C).
- $X_{\sigma s}, X_m$ stator leakage and magnetizing reactance.

NOTE 1 When using the equivalent circuit method in 6.4.4.4 and 8.2.2.4.3, all voltages, currents and impedances are per phase values for a three-phase machine in Y-connection; powers and reactive powers are per complete machine.

NOTE 2 For copper $\alpha_r = 1/235$ and for aluminium $\alpha_r = 1/225$.

NOTE 3 A method to obtain the model parameters is provided in 8.2.2.4.3.

6.4.4.4.2 Tests at reduced frequency

With the rotor of the machine locked, supply power from a three-phase, adjustable-frequency converter capable of furnishing up to 25 % of the rated frequency at rated current. An average value of impedance shall be obtained from the position of the rotor relative to the stator.

NOTE 1 During the tests the frequency converter, either a machine set or a static converter, should supply practically sinusoidal current at the output.

NOTE 2 The rotor windings of wound-rotor machines should be short-circuited for the test.

Supply rated current and take readings for at least three frequencies, including one at less than 25 % and the others between 25 % and 50 % rated frequency. During this quick test the stator winding temperature increase should not exceed 5 K.

For at least three frequencies, record: U , I , f , P_1 , R_s , θ_c , θ_w .

6.4.4.4.3 Tests at rated frequency

Impedance values can also be determined from the following tests.

- a) Reactance from a rated frequency, reduced voltage, rated current locked rotor test: record voltage, current, power, frequency and temperatures.
- b) Rotor running resistance:
 - 1) from a stabilized rated frequency, rated voltage reduced load test. Record voltage, power, current, slip and temperatures for the load point; or
 - 2) from an open-circuit test, following a stabilized rated frequency, rated voltage no-load operation. Record the open-circuit voltage and winding temperature as a function of time after the motor is tripped from a no-load test.

NOTE This test assumes relatively low current displacement in the rotor.

6.4.5 Additional load losses

6.4.5.1 Single supply back-to-back-test (d.c. machines)

This method allows the determination of the d.c. component of the additional losses when two identical d.c. machines are available. They shall be coupled and electrically connected together and supplied by a d.c. source, the machine acting as a generator with a booster generator in series (see Figure 6).

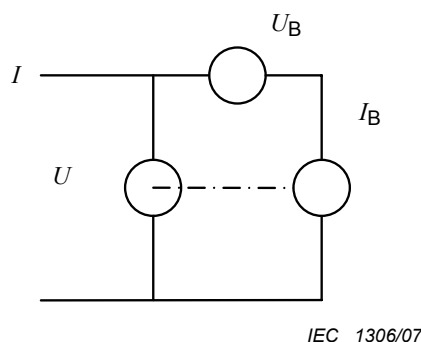


Figure 6 – Sketch for single supply back-to-back, additional losses, d.c. machines

If the machines are designed for motoring operation, the supply shall deliver rated voltage and rated current to the machine acting as motor. In the case of machines designed for generating operation, the supply voltage shall be adjusted to rated voltage and rated current at the machine acting as generator. The motor and the generator shall be operated with the flux required to produce the e.m.f. corresponding to the test load.

NOTE The voltage supply mainly covers the no-load losses, the booster mainly covers the load losses.

In the case of machines with shaft driven exciters, the excitation windings shall be separately excited for this test, with the exciters disconnected from their supply and the excitation winding.

When temperatures have stabilized, record: U , I , U_B , I_B , $U_{e,M}$, $I_{e,M}$, $U_{e,G}$, $I_{e,G}$, n , θ_c .

6.4.5.2 AC losses (converter-fed d.c. machines)

The losses are obtained from a load test with the machine supplied by an appropriate rectifier. See also IEC 60034-19.

Record:

- P_1 the a.c. power supplied to the machine;
- I the a.c. r.m.s. current component; and
- θ_w the temperatures of the windings in galvanic contact with the armature circuit.

NOTE For series-wound motors, a small amount of the a.c. power input contributes to the developed motor torque. This amount is usually so small that it can be neglected.

6.4.5.3 Load test with torque measurement (induction machines)

For the determination of the additional losses, the load test according to 6.4.4.2 shall be performed by additionally providing a torque measurement device fulfilling the requirements of 5.5.4.

For each load point, additionally record the torque: T .

6.4.5.4 Test with rotor removed and reverse rotation test (induction machines)

6.4.5.4.1 General

This is a combined test requiring two individual tests:

- a) with the rotor removed (for the fundamental frequency additional losses);
- b) with the machine rotating at synchronous speed opposite to the magnetic field, driven by external means (for the higher frequencies losses).

During both tests, the stator shall be supplied by a balanced polyphase current of rated frequency for four currents between 25 % and 100 % rated current, and two currents above and of not more than 150 % rated current. Calculate the (rotor) load current I_L :

$$I_L = \sqrt{I^2 - I_0^2}$$

where

I is the value of stator current during the test giving a desired load current;

I_0 is the no-load current at rated voltage.

6.4.5.4.2 Test with the rotor removed

For this test, all parts in which eddy currents might be induced, for example end shields and bearing parts, shall be in place. Apply load current.

For each load current, record (symbols indexed "rm"): $P_{1,rm}$, $I_{L,rm}$, R_{rm} , $\theta_{w,rm}$.

6.4.5.4.3 Reverse-rotation test

For this test, couple a completely assembled machine to a driving motor with an output capability of not less than rated total loss and not more than five times the rated losses of the machine to be tested. When a torquemeter is used for the determination of the shaft power, its maximum torque shall not exceed ten times the torque corresponding to the rated total loss of the machine to be tested. For wound-rotor machines, the rotor terminals shall be short-circuited.

Drive the machine under test at synchronous speed in the direction reverse to the rotation when fed in normal phase sequence:

- without voltage applied to the stator until friction losses are stabilized. Record: $P_{0,rr}$ supplied by the driving machine at $I = 0$;
- with voltage applied to the stator to obtain stator current values equal to those for the test with rotor removed. For all test currents, record (symbols indexed "rr"): $I_{L,rr}$, R_{rr} , $P_{1,rr}$, $\theta_{w,rr}$ for the test motor; $P_{D,rr}$ of the drive motor.

NOTE The low power factor of the tests may require a phase error correction to all wattmeter readings.

6.4.5.5 Eh-star test (induction machines)

This test requires operating the uncoupled motor with unbalanced voltage supply. The test circuit is according to Figure 7.

Motors rated for and connected in delta-connection shall be reconnected to star-connection during this test. The star-point must not be connected to system neutral or earth, to avoid zero-sequence currents.

The third motor-phase shall be connected to the power-line by means of a resistor R_{eh} (see Figure 7) having approximately the following typical value:

- for motors rated for star-connection:
$$R'_{eh} = \frac{U_N}{\sqrt{3} \cdot I_N} \cdot 0.2$$
- for motors rated for delta-connection:
$$R'_{eh} = \frac{\sqrt{3} \cdot U_N}{I_N} \cdot 0.2$$

The resistor R_{eh} used during the test shall be adjusted so that the positive sequence current $I_{(1)}$ stays below 30 % of negative sequence current $I_{(2)}$ and the speed stays in the range of typical motor speeds near rated speed (see below). It is recommended to begin the test with an actual resistor R_{eh} that differs no more than 20 % from the typical value R'_{eh} .

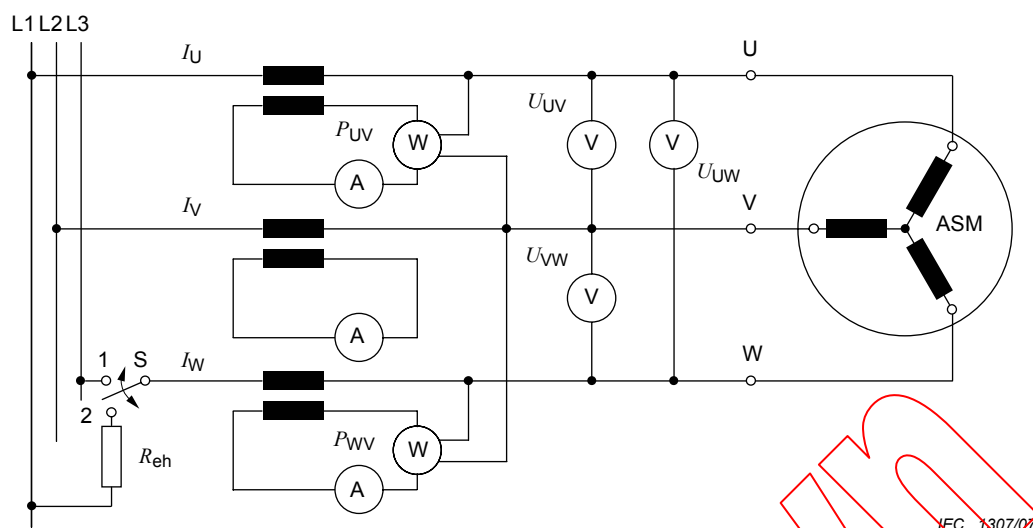


Figure 7 – Eh-star test circuit

Test current I_t is given by

- for motors rated for star-connection:
$$I_t = \sqrt{I_N^2 - I_0^2}$$
- for motors rated for delta-connection:
$$I_t = \frac{\sqrt{I_N^2 - I_0^2}}{\sqrt{3}}$$

Test voltage U_t is given by

- for motors rated for star-connection:
$$U_t = U_N$$
- for motors rated for delta-connection:
$$U_t = U_N \cdot \sqrt{3}$$

Prior to the test the no-load losses have to be stabilised according to 6.4.2.2.

Measure and record the resistance between the terminals V and W (R_{VW}) before and after the complete test.

In order to avoid excessive unequal heating of the three phases, the test shall be conducted on a cold machine and carried out as quickly as possible.

Larger motors can only be started without the R_{eh} resistor (switch S to position 1, see Figure 7) at reduced voltage (25 % – 40 % U_N). After run-up connect R_{eh} by switching to position 2.

Smaller motors should start-up with resistor R_{eh} already connected. In this case, the switch is not needed.

Vary the supply voltage for six test points. The test points shall be chosen to be approximately equally spaced between 150 % and 75 % of rated phase current measured in phase V (I_V). When starting the test, begin with the highest current and proceed in descending order to the lowest current.

The line-to-line resistance R_{VV} for 100 % test current and lower currents shall be the value determined after the lowest reading (at the end of the test). The resistance used for currents higher than 100 % shall be determined as being a linear function of current, using the readings before and after the complete test. The test resistance is determined using the extrapolation according to 5.7.1.

Record for each test point: $I_U, I_V, I_W, U_{UV}, U_{VW}, U_{WU}, P_{UV}, P_{WV}, n$

NOTE 1 It is understood that in this test no averaging of phase resistances is permissible.

NOTE 2 Resistances may also be determined by measuring the stator winding temperature using a temperature-sensing device installed on the winding. Resistances for each load point may then be determined from the temperature of the winding at that point in relation to the resistance and temperature measured before the start of the test.

NOTE 3 Some commonly used integrated wattmeters symmetrize the three phases by an internal virtual star connection. However, in this test the power supply is intentionally unsymmetrical. Therefore, it is essential to ensure that neither earthing of the star point nor a virtual star point is established. The provided test circuit (see Figure 7) should be strictly applied.

In order to achieve accurate results the slip shall be not greater than twice the rated slip for all currents, in other words: $n > n_{\text{syn}} - 2 \cdot (n_{\text{syn}} - n_N)$. If this condition cannot be met the test shall be repeated with an increased value of R_{eh} . If the motor still runs unstable at currents below 100 % of rated phase current these test points should be omitted.

6.4.5.6 Short-circuit test and uncoupled motor test (synchronous machines)

6.4.5.6.1 Short-circuit test with coupled machine

Couple the machine under test with its armature winding short-circuited to a drive machine, with provisions to record the torque using a torquemeter (see 6.3.1.2) or dynamometer (see 6.3.1.3). Operate at rated speed and excited so that the current in the short-circuited primary winding is equal to the rated current.

NOTE In the case of a machine with a shaft driven exciter (see 3.4.3.3 a)), the machine should be separately excited and the exciter disconnected from its supply and from the excitation winding.

The sum of the load losses and the additional losses is assumed to be temperature independent, and no correction to a reference temperature is made. It is assumed that the additional losses vary as the square of the stator current.

Record: T, n, I .

Excitation system values are according to 6.2.

6.4.5.6.2 Test with uncoupled machine

The machine is operated as a synchronous motor at a fixed voltage, preferably about 1/3 normal or at the lowest value for which stable operation can be obtained. The armature current is varied by control of the field current. The armature current should be varied in about six steps between 125 % and 25 % of rated current and should include one or two points at very low current. The maximum test current value, traditionally set at 125 %, should be obtained from the manufacturer since sometimes stator cooling will not permit operation in excess of 100 % rated current without damage. The highest readings should be taken first to secure more uniform stator winding temperatures during the test.

Record: P_1 , I , U .

Excitation system values are according to 6.2.

NOTE For large machines, the maximum step may be limited to 60 % to 70 % of rated armature current,.

7 Determination of efficiency (direct current machines)

7.1 Determination from direct measurement

7.1.1 Torque measurement test

When tested according to 6.3.1, the efficiency is:

$$\eta = \frac{P_2}{P_1 + P_{1E}}$$

According to 6.3.1.1, input power P_1 and output power P_2 are as follows:

- in motor operation: $P_1 = P_{el}$; $P_2 = P_{mech}$;
- in generator operation: $P_1 = P_{mech}$; $P_2 = P_{el}$

where

P_{el} ; T ; and n are according to 6.3.1.2, 6.3.1.3;

$$P_{mech} = 2\pi \times T \times n$$

P_{1E} is according to 6.2, using 3.4.3.3 and 3.4.3.4.

NOTE Excitation circuit losses not supplied by P_{1E} are mechanically covered from the shaft.

7.1.2 Dual supply back-to-back test

When identical machines are run at essentially the same rated conditions, the efficiency shall be calculated from half the total losses and the average input power of the motor and generator as follows:

$$\eta = 1 - \frac{P_T}{\frac{P_1 + P_2}{2} + P_{1E}}$$

where

$$P_T = \frac{1}{2}(P_1 - P_2) + P_{1E} \quad ; \quad P_{1E} = \frac{1}{2}(P_{1E,M} + P_{1E,G})$$

and

P_1 and P_2 are according to 6.3.2;

P_{1E} is according to 6.2, using 3.4.3.3 and 3.4.3.4.

7.2 Determination from indirect measurement

7.2.1 Total losses

7.2.1.1 Single supply back-to-back test procedure

When identical machines are run at essentially rated conditions, the efficiency is calculated by assigning half the total losses to each machine.

Calculate the efficiency from

$$\eta = 1 - \frac{P_T}{P_M + P_{1E}}$$

where

P_M is the power absorbed at the terminals of the machine acting as the motor (excluding excitation power), according to 6.4.1.1;

P_T is the total losses, defined as half the total absorbed;

P_{1E} is the excitation power supplied by a separate source (for machines with a booster generator see 6.4.1.1.2):

$$P_T = \frac{1}{2}(U_M \times I_1 + U_B \times I_B) + P_{1E} ; \quad P_{1E} = \frac{1}{2}(P_{1E,M} + P_{1E,G})$$

7.2.2 Summation of separate losses

7.2.2.1 Efficiency

The efficiency is determined from

$$\eta = \frac{P_1 + P_{1E} - P_T}{P_1 + P_{1E}} = \frac{P_2}{P_2 + P_T}$$

where

P_1 is the input power excluding excitation power from a separate source;

P_2 is the output power;

P_{1E} is the excitation power supplied by a separate source;

P_T is according to 7.2.2.2.

NOTE 1 Usually, the first expression is preferred for a motor, the second for a generator.

NOTE 2 P_T includes the excitation power P_e (see 6.2) of the machine where applicable.

7.2.2.2 Total losses

The total losses shall be taken as the sum of the separate losses 7.2.2.3 to 7.2.2.6 consisting of

$$P_T = P_k + P_a + P_b + P_{LL} + P_e$$

$$P_e = P_f + P_{Ed}$$

where

P_a is the armature-winding loss;

P_b is the brush loss;

P_k is the constant losses;

P_{LL} is the additional losses;

P_f is the excitation (field winding) loss;

P_{Ed} is the exciter loss.

7.2.2.3 Constant losses

7.2.2.3.1 Determination of constant losses

Determine the constant losses from the following equation:

$$P_k = P_0 - P_a$$

where

$$P_a = I_0^2 \times R_0;$$

I_0 and R_0 are for each value of voltage recorded according to 6.4.2.3.

When resistance measurement is impracticable due to very low resistances, calculated values are permissible, corrected to the expected winding temperature.

NOTE In the armature losses P_a , the following are included: compensating windings, commutating pole windings and shunt resistors (diverters). In the case of diverters in parallel with a series winding, the electrical winding losses may be determined using the total current and the resulting resistance.

7.2.2.3.2 Friction and windage losses (optional)

For each of the values of voltage 50 % or less from 6.4.2.3, develop a curve of constant losses (P_k) from 7.2.2.3.1 against voltage U_0^2 . Extrapolate a straight line to zero voltage. The intercept with the zero voltage axis is the windage and friction losses P_{fw} .

7.2.2.3.3 Iron losses (optional)

For each of the values of voltage between 60 % and 125 % from 6.4.2.3, develop a curve of constant losses (P_k) from 7.2.2.3.1 against voltage U_0 . The iron loss shall be taken for the inner voltage, at:

$$U_0 = U_N - (IR)_a - 2U_b \text{ in the case of a motor}$$

$$U_0 = U_N + (IR)_a + 2U_b \text{ in the case of a generator}$$

where

U_N is the rated voltage;

$2U_b$ is the brush voltage-drop as given in 7.2.2.4.2;

I is the current of the desired load point;

R is the resistance of all windings of the armature circuit at full-load temperature.

Determine the iron loss from

$$P_{fe} = P_k - P_{fw}$$

where

P_{fw} is from 7.2.2.3.2.

7.2.2.4 Load losses

7.2.2.4.1 Armature circuit winding losses

For each load recorded determine the armature-circuit-windings losses:

$$P_a = I^2 \times R$$

where

I and R are according to 5.7.2 and 6.4.4.2, with R taking all windings in the armature circuit into account.

7.2.2.4.2 Electrical brush losses

Determine brush losses using an assigned voltage drop per brush:

$$P_b = 2 \times U_b \times I$$

where

I is the armature current at the rating considered;

U_b is the assumed voltage drop per brush depending on brush type:

1,0 V for carbon, electrographitic or graphite;

0,3 V for metal-carbon.

7.2.2.5 Excitation circuit losses

In the case of a load test according to 6.4.3.1, the excitation winding losses result from the measured voltage and current as follows:

$$P_f = U_e \times I_e$$

Without a load test, the excitation winding losses P_e shall be calculated from $I_e^2 \times R_f$, where R_f is the resistance of the shunt excitation winding (or separately excited winding), corrected to the reference temperature specified in 5.7.3 and I_e is the excitation current according to the following list.

- For shunt connected or separately excited generators with or without commutating poles, I_e is 110 % of the excitation current corresponding to no-load at a voltage equal to the rated voltage plus ohmic drop in the armature circuit (armature, brushes and commutating windings if any, see also 7.2.2.4.1) at the current of the specific load point.
- For compensated shunt or separately excited generators, I_e is the excitation current corresponding to no-load at a voltage equal to the rated voltage plus ohmic drop in the armature circuit at the current of the specific load point.
- For level-compounded generators, I_e is the excitation current for the rated no-load voltage.
- For over-compounded and under-compounded generators, and special types of generator not covered by items a) to c), I_e is subject to agreement.
- For shunt wound motors, I_e is equal to no-load excitation current corresponding to the rated voltage.

The exciter losses P_{Ed} according to 6.4.3.3, if determined from tests, are

$$P_{Ed} = (T_E - T_{E,0}) \times 2\pi n + P_{IE} - U_e \times I_e$$

where

$T_{E,0}$ is the torque with the exciter unexcited.

In all other cases, calculated losses shall be used.

7.2.2.6 Additional load losses

7.2.2.6.1 DC losses (single supply back-to-back-test)

Determine the additional losses per machine at rated current from the measured values of 6.4.5.1.

$$P_{LL} = \frac{1}{2} (P_1 - \Sigma P_k - \Sigma P_a - P_{con} - 2U_b(I + I_B) - 2I_B U_b)$$

where

$P_1 = U_M \times I_1 + U_B \times I_B$ is the power from supply and booster; see Figure 3.

ΣP_k is the sum of constant losses of both machines from 7.2.2.3;

ΣP_a is the sum of the resistance losses of both armature circuits from 7.2.2.4.1;

P_{con} is the loss in cable connections.

For determination of losses for other load points, apply the factors as described in Table 5.

7.2.2.6.2 AC losses

The additional losses due to the a.c. part of the supply voltage result from:

$$P_{LL} = P_1 - I^2 \times R_a$$

where

R_a is the d.c. resistance of the armature circuit at rated load temperatures;

P_1 and I are according to 6.4.5.2.

7.2.2.6.3 Losses from assigned allowance (d.c. losses) and calculations (a.c. losses)

It is assumed that the d.c. losses vary as the square of the current, and that their total value at maximum rated current is:

- a) for uncompensated machines:
 - 1 % of the rated input power for motors;
 - 1 % of the rated output power for generators;
- b) for compensated machines:
 - 0,5 % of the rated input power for motors;
 - 0,5 % of the rated output power for generators.

For constant speed machines, the rated power is the power with maximum rated current and maximum rated voltage.

For variable speed motors where the speed change is obtained by applied voltage, the rated input power is defined at each speed as being the input power when the maximum rated current is associated with the applied voltage of the particular speed considered.

For variable speed motors where the increase in speed is obtained by weakening the field, the rated input power is defined as being the input power when the rated voltage is associated with the maximum rated current. For variable speed generators where the voltage is maintained constant by varying the field, the rated output power is defined as being the output power, which is available at the terminals at rated voltage and maximum rated current. The allowances for additional losses at the speed corresponding to the full field shall be as specified above under a) and b). The allowances for additional losses at other speeds shall be calculated using the appropriate multiplying factors given in Table 5.

Table 5 – Multiplying factors for different speed ratios

Speed ratio	Factor
1,5:1	1,4
2:1	1,7
3:1	2,5
4:1	3,2

The speed ratio in the first column of Table 5 shall be taken as the ratio of actual speed under consideration to the minimum rated speed for continuous running.

For speed ratios other than those given in Table 5, the appropriate multiplying factors may be obtained by interpolation.

For motors supplied by static power converters, whenever the current ripple factor (see IEC 60034-1) of the armature current exceeds 0,1, the additional losses caused by the a.c. component of the armature current (see 7.2.2.6.2) shall be considered in addition to the losses specified above.

8 Determination of efficiency (induction machines)

8.1 Determination from direct measurement

8.1.1 Torque measurement test

When tested according to 6.3.1, the efficiency is:

$$\eta = \frac{P_2}{P_1}$$

Input power P_1 and output power P_2 are according to 6.3.1.1:

- in motor operation: $P_1 = P_{el}$; $P_2 = P_{mech}$;
- in generator operation: $P_1 = P_{mech}$; $P_2 = P_{el}$

where

P_{el} , T and n are according to 6.3.1.2 and, 6.3.1.3.

$$P_{mech} = 2\pi \times T \times n.$$

8.1.2 Dual supply back-to-back test

When identical machines are run at essentially the same rated conditions, the efficiency shall be calculated from half the total losses and the average input power of the motor and generator as follows:

$$\eta = 1 - \frac{P_T}{\frac{P_1 + P_2}{2}}$$

where

$$P_T = \frac{1}{2}(P_1 - P_2)$$

P_1 and P_2 are according to 6.3.2.

8.2 Determination from indirect measurement

8.2.1 Total losses from single supply back-to-back test

When identical machines are run at essentially rated conditions, the efficiency is calculated by assigning half the total losses to each machine.

Calculate the efficiency from

$$\eta = 1 - \frac{P_T}{P_M}$$

where

P_M is the power absorbed at the terminals of the machine acting as motor according to 6.4.1.1;

P_T is the total losses, defined as half the total absorbed, for wound-rotor induction machines measured according to 6.4.1.1.3 as follows: $P_T = \frac{1}{2}(P_1 + P_r)$

8.2.2 Summation of separate losses

8.2.2.1 Efficiency

The efficiency is determined from

$$\eta = \frac{P_1 - P_T}{P_1} = \frac{P_2}{P_2 + P_T}$$

NOTE Usually, the first expression is preferred for a motor, the second one for a generator.

where

P_1 is the input power from a rated load test according to 6.4.4.1;

P_2 is the output power;

P_T is according to 8.2.2.2.

8.2.2.2 Total losses

The total losses shall be taken as the sum of 8.2.2.3 (constant losses), 8.2.2.4 (load losses) and 8.2.2.5 (additional load losses):

$$P_T = P_k + P_s + P_r + P_{LL}$$

8.2.2.3 Constant losses

8.2.2.3.1 General

Subtracting the no-load winding losses (at the temperature during the no-load test) from the no-load input power gives the constant losses that are the sum of the friction, windage, and iron losses. Determine the constant losses for each value of voltage recorded in 6.4.2.

$$P_k = P_0 - P_s = P_{fw} + P_{fe}$$

where

$$P_s = 1,5 \times I_0^2 \times R_{llo} \text{ (see 6.4.2.3)}$$

8.2.2.3.2 Friction and windage losses

From the no-load loss points determined above, use all those that show no significant saturation effect and develop a curve of constant losses (P_k) against the voltage squared (U_0^2). Extrapolate a straight line to zero voltage. The intercept with the zero voltage axis is the friction and windage losses P_{fw} .

NOTE Windage and friction losses are considered to be independent of load and the same windage and friction value may be used for each of the load points.

8.2.2.3.3 Iron losses

From the values of voltage between 60 % and 125 % of rated voltage, plot a curve of $P_{fe} = P_k - P_{fw}$ against voltage U_0 . The iron losses of the desired load point are taken from the curve at voltage U_r which takes the resistive voltage drop in the primary winding into account:

$$U_r = \sqrt{\left(U - \frac{\sqrt{3}}{2} \times I \times R \cos \varphi \right)^2 + \left(\frac{\sqrt{3}}{2} \times I \times R \sin \varphi \right)^2}$$

where

$$\cos \varphi = \frac{P_1}{\sqrt{3} \times U \times I}; \quad \sin \varphi = \sqrt{1 - \cos^2 \varphi}$$

U , P_1 , I and R are according to 6.4.4.2.

8.2.2.4 Load losses

8.2.2.4.1 From a load test

8.2.2.4.1.1 General

Load losses for determination of rated efficiency shall use the inputs from 6.4.4.1.

Load losses for determination of additional load losses shall use the inputs from 6.4.4.2.

8.2.2.4.1.2 Stator-winding losses and temperature correction

The uncorrected stator-winding losses at each of the load points are:

$$P_s = 1,5 \times I^2 \times R$$

where

I and R are determined in 6.4.4.1.

Corrected stator-winding losses at any load point are determined using the stator winding resistance R_N from the rated load test, corrected to a reference coolant temperature of 25 °C:

$$P_{s,\theta} = P_s \times k_\theta$$

where

k_θ is according to 5.7.3.

8.2.2.4.1.3 Rotor winding losses and temperature correction

For the uncorrected rotor winding losses for each of the load points use the equation:

$$P_r = (P_1 - P_s - P_{fe}) \times s$$

where

$$s = 1 - \frac{p \times n}{f}$$

P_1 , n and f are according to 6.4.4.1;

P_s is according to 8.2.2.4.1.2;

P_{fe} is according to 8.2.2.3.3.

The corrected rotor winding losses at any load point are determined using the value of slip for each of the points corrected to a reference coolant temperature of 25 °C and using the corrected value of the stator winding losses (see 8.2.2.4.1.2) for each of the points.

$$P_{r,\theta} = (P_1 - P_{s,\theta} - P_{fe}) \times s_\theta$$

where

$P_{s,\theta}$ is according to 8.2.2.4.1.2;

P_{fe} is according to 8.2.2.3.3;

$s_\theta = s \times k_\theta$ is the slip corrected to a reference coolant temperature of 25 °C (see 5.7.3);

k_θ is according to 5.7.3.

8.2.2.4.1.4 Electrical losses in brushes (wound-rotor only)

These losses are included in 8.2.2.4.1.3.

Determine brush loss per phase using an assumed voltage drop per brush as follows:

$$P_b = N \times U_b \times I_2$$