PAKISTAN STANDARD

ROTATING ELECTRICAL MACHINES –
PART 2-1: STANDARD METHODS FOR DETERMINING LOSSES AND EFFICIENCY FROM TESTS

PAKISTAN STANDARDS AND QUALITY CONTROL AUTHORITY,
STANDARDS DEVELOPMENT CENTRE,
PSQCA Complex Street 7 A Block –3
Scheme –36 Gulistan –e- johar Karachi

ROTATING ELECTRICAL MACHINES –
PART 2-1: STANDARD METHODS FOR DETERMINING
LOSSES AND EFFICIENCY FROM TESTS

0. FOREWORD

0.1 This Pakistan Standard was adopted by the authority of the Board of Directors for Pakistan Standards and Quality Control Authority after approval by the Technical Committee for "Rotating Electrical Machines Part 2-1: Standard method for determining losses and efficiency from tests" had been approved and endorsed by the Electrotechnical National Standards Committee 28 December 2016.

0.2 This Pakistan Standard was adopted on the basis of IEC: 60034-2-1-2007 since IEC Standard has been revised in 2014, hence it is deemed necessary to adopt the International standard to keep abreast with the latest technology and as par with IEC standard.

0.3 This Pakistan Standard is an adoption of IEC: 60034-2-1-2014 Rotating Electrical Part 2-1: Standard method for determining losses and efficiency from test**s** and its use hereby acknowledged with thanks.

0.4 This standard is subject to periodical review in order to keep pace with the development in industry. Any suggestions for improvement shall be recorded and placed before the revising committee in due course.

0.5 This standard is intended chiefly to cover the technical provisions relating to this standard and it does not include all the necessary provisions of a Contract.

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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 form 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 addititional 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, ºC

θ_a is the ambient temperature, ºC

θ_c primary coolant inlet temperature, ºC

θ_w is the winding temperature, ºC

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:

a) 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;

b) 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;

c) 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 ≥ 1,25 × 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 ≤ 5 × 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 ±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 ±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 ±0,5 % for general testing or not greater than ±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 ±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 ±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 s^{-1} x 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, $R = R_{\mathrm{ll}}$ 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, $R_{\mathrm{r,ll}}$ 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):

a) temperature determined from the rated load test resistance R_{N} by the extrapolation procedure as described in 5.7.1;

b) temperature measured directly by either ETD or thermocouple;

c) temperature determined according to a) on a duplicate machine of the same construction and electrical design;

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

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.

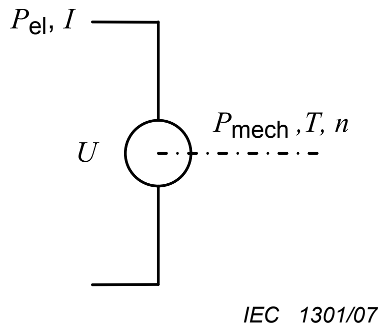

Figure 1 – Sketch for torque measurement test

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, θ_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, θ_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.

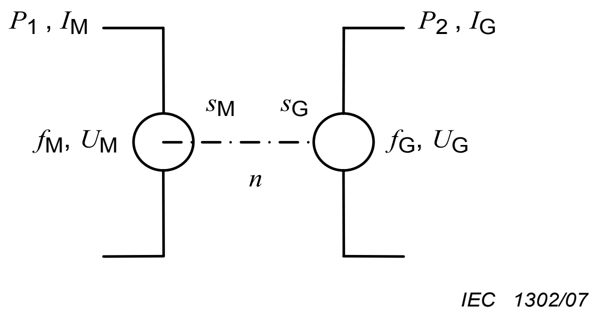

Figure 2 – Sketch for dual supply back-to-back test
(for synchronous machines: $I_M = I_G$, $f_M = f_G$)

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 φ_M, cos φ_G, θ_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.

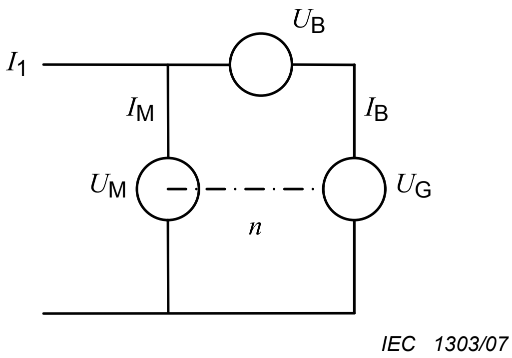

Figure 3 – Sketch for single supply back-to-back test, d.c. machines

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).

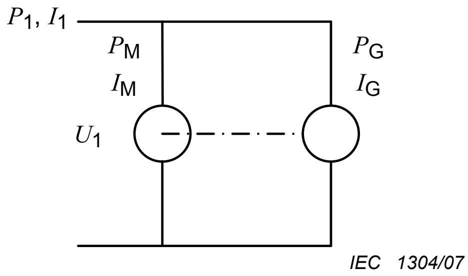

Figure 4 – Sketch for single supply back-to-back test, synchronous machines

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 machines, R_o 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 lossses 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 $X'_{\sigma r}$.

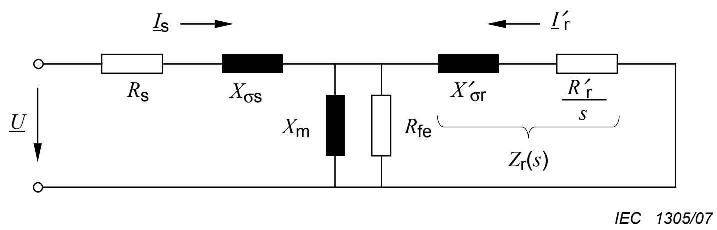

Figure 5 – Induction machine, T-model with equivalent iron loss resistor

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 α_r = 1/235 and for aluminium α_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).

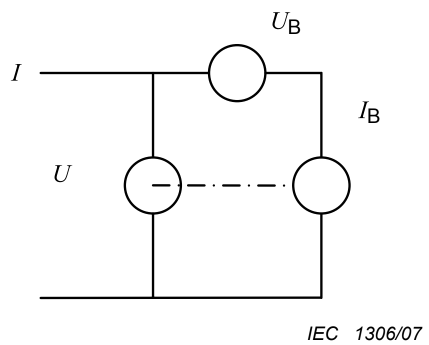

Figure 6 – Sketch for single supply back-to-back, additional losses, d.c. machines

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:

a) without voltage applied to the stator until friction losses are stabilized. Record: $P_{0,rr}$ supplied by the driving machine at $I = 0$;
b) 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}.

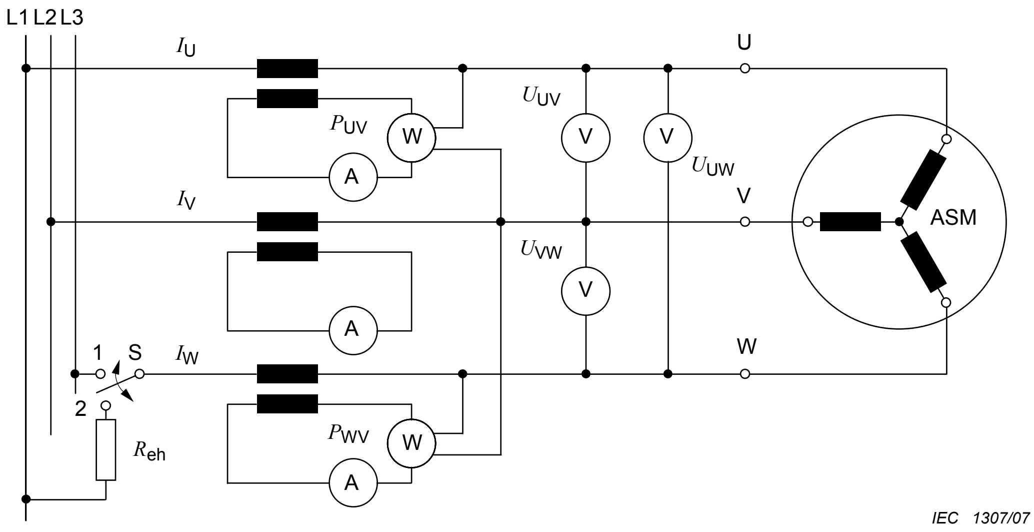

Figure 7 – Eh-star test circuit

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: $I_t = \dfrac{\sqrt{{I_N}^2 - {I_0}^2}}{\sqrt{3}}$

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_{VW} 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: $n > n_{syn} - 2\cdot(n_{syn} - n_N)$. 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):

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

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:

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

$U_0 = U_N + (IR)_a + 2U_b$ 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.

a) 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.

b) 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.

c) For level-compounded generators, I_e is the excitation current for the rated no-load voltage.

d) 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.

e) 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

$$P_{Ed} = \left(T_E - T_{E,0}\right) \times 2\pi n + P_{1E} - U_e \times I_e$$

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.

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

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: $P_T = \frac{1}{2}\left(P_1 + P_r\right)$

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):

$$P_{\mathrm{T}} = P_{\mathrm{k}} + P_{\mathrm{s}} + P_{\mathrm{r}} + P_{\mathrm{LL}}$$

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.

$$P_{\mathrm{k}} = P_0 - P_{\mathrm{s}} = P_{\mathrm{fw}} + P_{\mathrm{fe}}$$

where $P_{\mathrm{s}} = 1,5 \times I_0{}^2 \times R_{\mathrm{ll0}}$ (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 $P_{\mathrm{fe}} = P_{\mathrm{k}} - P_{\mathrm{fw}}$ 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:

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

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:

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

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.

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

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:

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

where

N is the total number of phases carrying I;

I_2 is the secondary current (not referred to the primary);

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

NOTE For I_2 designed value may be used.

8.2.2.4.2 Losses from load test at reduced voltage

From the result of the test 6.4.4.3 calculate the current under load and the absorbed power at rated voltage:

$$\underline{I} = \underline{I}_{\text{red}} \frac{U_{\text{N}}}{U_{\text{red}}} + \Delta \underline{I}_0$$

where

$$\Delta \underline{I}_0 = -j(|\underline{I}_0| \sin \varphi_0 - |\underline{I}_{0,\text{red}}| \frac{U_{\text{N}}}{U_{\text{red}}} \sin \varphi_{0,\text{red}})$$

$$P_1 = P_{1,\text{red}} \times \left(\frac{U_{\text{N}}}{U_{\text{red}}} \right)^2$$

NOTE Underlined current symbols indicate vectors (see Figure 8).

By means of the values I and P_1 thus determined, and with the slip measured at reduced voltage, it is possible to calculate the load losses, similar to 8.2.2.4.1.

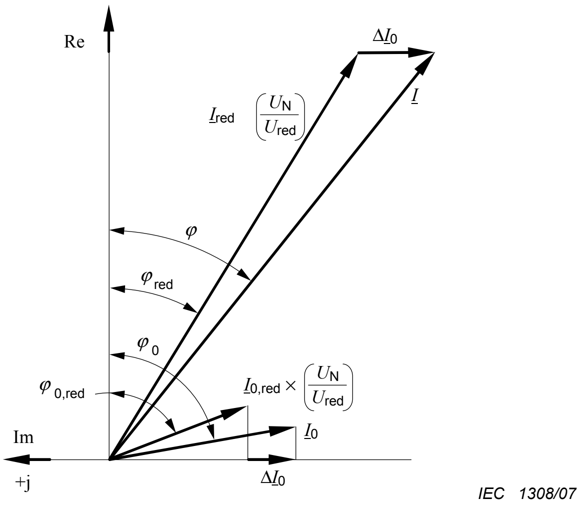

Figure 8 – Vector diagram for obtaining current vector from reduced voltage test

8.2.2.4.3 Losses from equivalent circuit method

8.2.2.4.3.1 Values from measurements

The method is based on the T-model circuit (see 6.4.4.4 and Figure 5).

NOTE When using the equivalent circuit method, 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.

The procedure described in this subclause is based on the method in 6.4.4.4.2. When using the method in 6.4.4.4.3 notice the following deviations:

a) the reactances are calculated in the same manner as in 8.2.2.4.3.2;
b) the rotor running resistance is determined:
   - using the test described in 6.4.4.4.3 a)

     by reverse calculation using the equivalent circuit in Figure 5, assuming a value for R_r'. Adjust the value of R_r' until the calculated power is within 0,1 % of the measured power, or the calculated current is within 0,1 % of the measured current;
   - using the test described in 6.4.4.4.3 b)

     by determining the time constant from the slope of the plot of the decaying voltage and the time on the open-circuit test. Determine R_r' from the equation:

$$R_r^{'} = \frac{\left(X_m + X_{\sigma r}^{'}\right)}{2\pi f \tau_0}$$

where

X_m is the magnetizing reactance;

$X_{\sigma r}$ is the rotor leakage reactance;

f is the line frequency;

τ_0 is the open-circuit time constant.

Correct the value of R_r' to the operating temperature from the test temperature.

Determine the reactive powers

– from the no-load test at rated voltage $U_0 = U_N$ and rated frequency (6.4.2.2)

$$P_{Q,0} = \sqrt{\left(3U_0 I_0\right)^2 - P_0^2}$$

– from the locked rotor test at reduced frequency (6.4.4.4.2)

$$P_{Q,lr} = \sqrt{\left(3U\,I\right)^2 - P_1^2}$$

where

U_0, I_0 and P_0, are phase voltage, phase current and supplied power from the no-load test at rated terminal voltage;

U, I and P_1 are phase voltage, phase current and supplied power from the locked rotor impedance test (see 6.4.4.4.3) at the frequencies f of this test.

8.2.2.4.3.2 Equivalent circuit parameters

The equivalent circuit parameters are determined in the following steps.

- Reactances

Calculate the reactances X_m from the no-load test and $X_{\sigma s,lr}$ from the locked-rotor test at 25 % rated frequency:

$$X_{\mathrm{m}} = \frac{3U_0^2}{P_{\mathrm{Q,0}} - 3I_0^2 X_{\sigma\mathrm{s}}} \times \frac{1}{\left(1 + \frac{X_{\sigma\mathrm{s}}}{X_{\mathrm{m}}}\right)^2} \qquad X_{\mathrm{s,lr}} = \frac{P_{\mathrm{Q,lr}}}{3I^2\left(1 + \frac{X_{\sigma\mathrm{s}}}{X'_{\sigma\mathrm{r}}} + \frac{X_{\sigma\mathrm{s}}}{X_{\mathrm{m}}}\right)} \times \left(\frac{X_{\sigma\mathrm{s}}}{X'_{\sigma\mathrm{r}}} + \frac{X_{\sigma\mathrm{s}}}{X_{\mathrm{m}}}\right)$$

$$X_{\sigma\mathrm{s}} = \frac{f_{\mathrm{N}}}{f_{\mathrm{lr}}} X_{\sigma\mathrm{s,lr}} \qquad X'_{\sigma\mathrm{r}} = \frac{X_{\sigma\mathrm{s}}}{X_{\sigma\mathrm{s}} / X'_{\sigma\mathrm{r}}}$$

Calculate using designed values as start values (see 6.4.4.4.1):

$$X_{\sigma\mathrm{s}}, X_{\mathrm{m}} \text{ and } \frac{X_{\sigma\mathrm{s}}}{X'_{\sigma\mathrm{r}}}.$$

Recalculate until X_{m} and $X_{\sigma\mathrm{s}}$ deviate less than 0,1 % from the values of the preceding step.

- Iron loss resistance

Determine the resistance per phase equivalent to the iron losses at rated voltage from

$$R_{\mathrm{fe}} = \frac{3U_{\mathrm{N,ph}}^2}{P_{\mathrm{fe}}} \times \frac{1}{\left(1 + \frac{X_{\sigma\mathrm{s}}}{X_{\mathrm{m}}}\right)^2}$$

where

P_{fe} is the iron losses according to 8.2.2.3.3 from P_0 at rated voltage.

- Rotor resistance

Determine the uncorrected rotor resistance for each locked rotor impedance test point:

$$R'_{\mathrm{r,lr}} = \left(\frac{P_1}{3I^2} - R_{\mathrm{s}}\right) \times \left(1 + \frac{X'_{\sigma\mathrm{r}}}{X_{\mathrm{m}}}\right)^2 - \left(\frac{X'_{\sigma\mathrm{r}}}{X_{\sigma\mathrm{s}}}\right)^2 \times \frac{X_{\sigma\mathrm{s.lr}}^2}{R_{\mathrm{fe}}}$$

where

R_{s} is the stator winding resistance per phase at the corresponding temperature θ_{W}.

NOTE If the rotor winding temperature deviates much from the stator winding temperature the method will become inaccurate.

The rotor resistance corrected to reference temperature (see 5.7.2, and Table 4) is, for each locked rotor impedance test frequency, given by

$$R''_{\mathrm{r,lr}} = R'_{\mathrm{r,lr}} \times \frac{1 + \alpha_{\mathrm{r}}\theta_{\mathrm{ref}}}{1 + \alpha_{\mathrm{r}}\theta_{\mathrm{W}}}$$

Plot a curve of $R''_{\mathrm{r,lr}}$ values against frequency f_{lr}. The intercept with f_{lr} = 0 results in the stator referred rotor resistance R'_{r}.

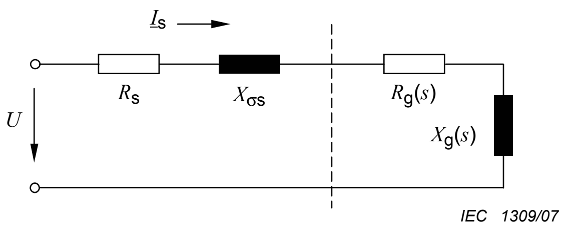

Figure 9 – Induction machines, reduced model for calculation

- Load dependent impedances

For each desired load point intermediate, calculate slip dependent impedance and admittance values (see Figure 9):

$$Z_r = \sqrt{\left(\frac{R_r'}{s}\right)^2 + X_{\sigma r}'^2} \qquad Y_g = \sqrt{\left(\frac{R_r'/s}{Z_r^2} + \frac{1}{R_{fe}}\right)^2 + \left(\frac{X_{\sigma r}'}{Z_r^2} + \frac{1}{X_m}\right)^2}$$

$$R_g = \frac{\dfrac{R_r'/s}{Z_r^2} + \dfrac{1}{R_{fe}}}{Y_g^2} \qquad X_g = \frac{\dfrac{X_{\sigma r}'}{Z_r^2} + \dfrac{1}{X_m}}{Y_g^2}$$

Calculate the resulting impedance seen from the terminals:

$$R = R_s + R_g \qquad X = X_{\sigma s} + X_g \qquad Z = \sqrt{R^2 + X^2}$$

where

s is the estimated slip;

R_s is the stator winding resistance per phase at reference temperature θ_{ref}.

8.2.2.4.3.3 Currents and losses

The performance values are determined in the following steps.

Determine: $I_s = \frac{U_N}{Z}$ stator phase current; $I_r' = I_s \frac{1}{Y_g Z_r}$ rotor phase current;

$P_\delta = 3 I_r'^2 \frac{R_r'}{s}$ air gap power transferred to the rotor; $P_{fe} = 3 I_s^2 \frac{1}{Y_g^2 R_{fe}}$ iron loss

$P_s = 3 I_s^2 R_s$; $P_r = 3 I_r'^2 R_r'$ stator and rotor winding loss

$P_{LL} = P_{LL,N} \left(\frac{I_r'}{I_{r,N}'}\right)^2$ additional load losses

from a value $P_{LL,N}$ at rated load, either assigned (8.2.2.5.3) or measured (8.2.2.5.2) or determined according to 8.2.2.5.4.

The total losses are:

$$P_T = P_s + P_{fe} + P_r + P_{LL} + P_{fw}$$

Since input and shaft power are $P_1 = 3I_s^2 R$ and $P_2 = P_1 - P_T$, the slip shall be corrected, and the current and loss calculations shall be repeated until P_2 for motor operation, or P_1 for generator operation, is near enough to the desired value.

The efficiency (motoring operation) results from:

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

8.2.2.5 Additional load losses

8.2.2.5.1 From a load test with torque measurement

8.2.2.5.1.1 Residual losses P_{Lr}

The residual losses shall be determined for each load point by subtracting from the input power: the output power, the stator winding losses at the resistance of the test, the iron losses, the windage and friction losses, and the rotor winding losses corresponding to the determined value of slip.

$$P_{Lr} = P_1 - P_2 - P_s - P_r - P_{fe} - P_{fw}\,;\; P_2 = 2\pi \times T \times n$$

where

P_1, T and n	are according to 6.4.4.2;
P_s	is according to 8.2.2.4.1.2;
P_{fe}	is according to 8.2.2.3.3;
P_{fw}	is according to 8.2.2.3.2;
P_r	is according to 8.2.2.4.1.3.

8.2.2.5.1.2 Smoothing of the residual loss data

The residual loss data shall be smoothed by using the linear regression analysis (see Figure 10) based on expressing the losses as a function of the square of the load torque according to the relationship:

$$P_{Lr} = A \times T^2 + B$$

where

T is according to 8.2.2.5.1.1;

A and B are constants determined according to 6.4.4.2 and 8.2.2.5.1.1 from at least six load points using the following equations:

A is the slope according to $A = \dfrac{i \times \Sigma\left((P_L) \times (T^2)\right) - \Sigma P_L \times \Sigma T^2}{i \times \Sigma\left(T^2\right)^2 - \left(\Sigma T^2\right)^2}$

B is the intercept according to $B = \dfrac{\Sigma P_L}{i} - A \times \dfrac{\Sigma T^2}{i}$

i is the number of load points summed.

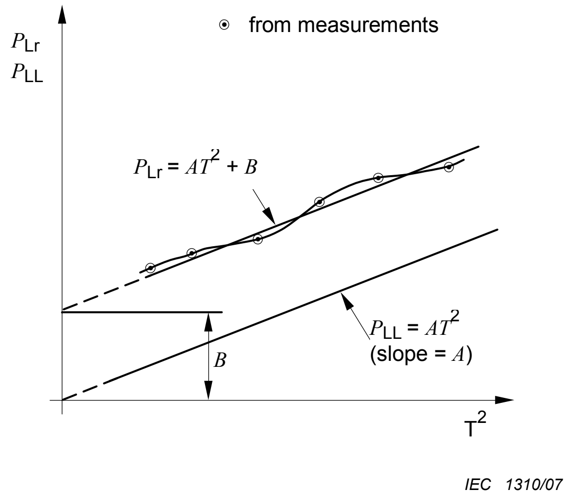

Figure 10 – Smoothing of the residual loss data

The correlation coefficient is according to $\gamma = \dfrac{i \times \Sigma\left(P_L \times T^2\right) - \left(\Sigma P_L\right) \times \left(\Sigma T^2\right)}{\sqrt{\left(i \times \Sigma\left(T^2\right)^2 - \left(\Sigma T^2\right)^2\right) \times \left(i \times \Sigma P_L^{\,2} - \left(\Sigma P_L\right)^2\right)}}$

When the correlation coefficient γ is less than 0,95, delete the worst point and repeat the regression. If γ increases to ≥ 0,95, use the second regression.; if γ remains less than 0,95, the test is unsatisfactory and errors in the instrumentation or test readings, or both, are indicated. The source of the error should be investigated and corrected, and the test (see 6.4.4.2) should be repeated.

8.2.2.5.1.3 Additional load losses P_{LL}

When the slope constant A is established, a value of additional load losses for each load point shall be determined by using the equation:

$$P_{LL} = A \times T^2$$

where

A and T are according to 8.2.2.5.1.2.

8.2.2.5.2 From a test with rotor removed and a reverse rotation test

Smooth the test values (see 6.4.5.4) of the stator powers $P_{1,rm}$ and $P_{1,rr}$, and the shaft power $\left(P_{D,rr} - P_{0,rr}\right)$ by applying a regression analysis to the log of powers and currents, resulting in the relationships below:

$$P_{1,rm} = A_{rm} \times I^{N1} + B_{L,rm};\quad P_{1,rr} = A_{rr} \times I^{N2} + B_{L,rr};\quad \left(P_{D,rr} - P_{0,rr}\right) = A_{D,rr} \times I^{N3} + B_{D,rr}$$

The smoothed powers will then be as follows:

$$P_{1,rm} = A_{rm} \times I^{N1};\quad P_{1,rr} = A_{rr} \times I^{N2};\quad \left(P_{D,rr} - P_{0,rr}\right) = A_{D,rr} \times I^{N3}$$

If the data are accurate, each curve will show a close square-law relationship between power and current.

The additional load losses are: $P_{\mathrm{LL}} = P_{\mathrm{LL,rm}} + P_{\mathrm{LL,rr}}$ where for each test current:

$P_{\mathrm{LL,rm}} = P_{\mathrm{1,rm}} - \left(3 \times I^2 \times R_{\mathrm{s,rm}}\right)$ is the fundamental frequency loss

where

$R_{\mathrm{s,rm}}$ is the stator phase resistance referred to the average of the temperatures $\theta_{\mathrm{W,rm}}$;

$P_{\mathrm{LL,rr}} = \left(P_{\mathrm{D,rr}} - P_{\mathrm{0,rr}}\right) - \left(P_{\mathrm{1,rr}} - P_{\mathrm{LL,rm}} - \left(3 \times I^2 \times R_{\mathrm{s,rr}}\right)\right)$ is the higher frequencies loss

where

$R_{\mathrm{s,rr}}$ is the stator phase resistance referred to the average of the temperatures $\theta_{\mathrm{W,rr}}$.

The additional load loss at a specified operating point can be determined in the following steps.

a) Calculate an approximate value for the load current I_{NL} corresponding to the rated value of stator line current:

$$I_{\mathrm{NL}} = \sqrt{I_{\mathrm{N}}^2 - I_0^2}$$

where

I_{N} is the rated value of stator line current;

I_0 is the value of no-load stator current.

b) For the value of load current I_{NL}, calculate a rated value of stray load loss P_{NLL} as follows:

$$P_{\mathrm{NLL}} = A_{\mathrm{Drr}} \times I_{\mathrm{NL}}^{N3} + 2A_{\mathrm{rm}} \times I_{NL}^{N1} - A_{\mathrm{rr}} \times I_{\mathrm{NL}}^{N2} - 6I_{\mathrm{NL}}^2 \times \left(R_{\mathrm{srm}} - 0.5R_{\mathrm{srr}}\right)$$

c) Calculate the value of load current I_{L} at any operating point:

$$I_{\mathrm{L}} = \sqrt{I^2 - I_0^2}$$

where

I is the stator line current at the operating point.

d) Calculate the stray load loss P_{LL} at the operating point:

$$P_{\mathrm{LL}} = P_{\mathrm{NLL}} \times \left(\frac{I_{\mathrm{L}}}{I_{\mathrm{NL}}}\right)^2$$

8.2.2.5.3 From assigned allowance

The value of additional load losses P_{LL} at rated load may be determined as a percentage of input power P_1 using the curve in Figure 11.

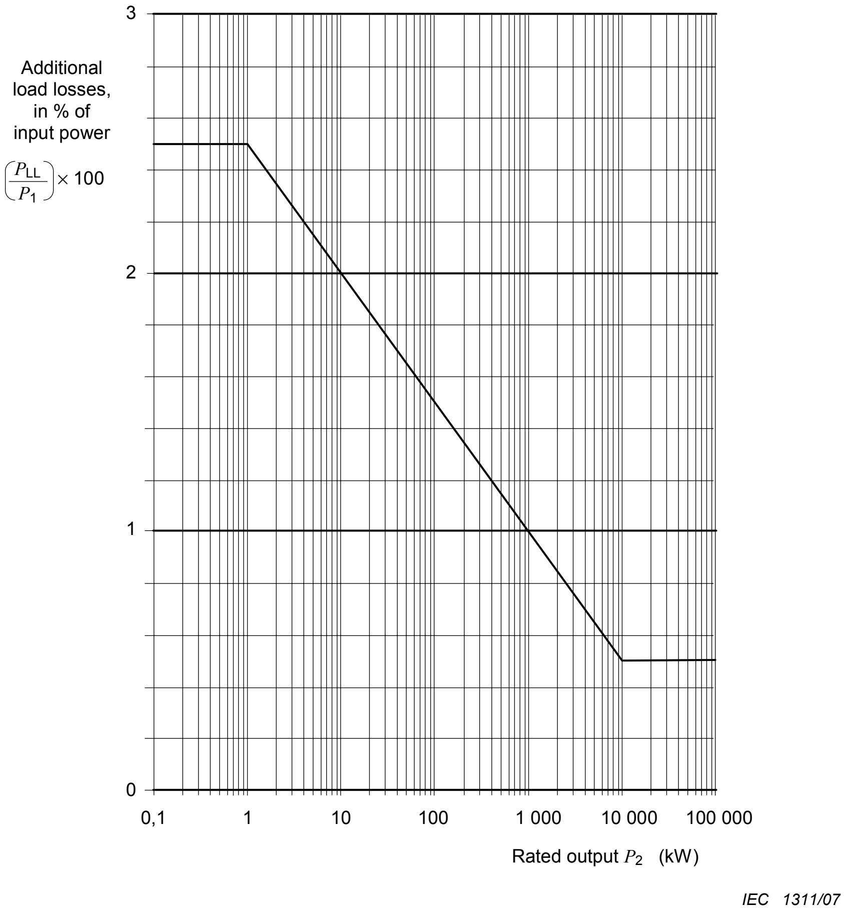

Figure 11 – Assigned allowance for additional load losses P_{LL}, induction machines

The values of the curve may be described by the following equations:

for $P_2 \leq 1$ kW $\qquad P_{LL} = P_1 \times 0{,}025$

for 1 kW < P_2 < 10 000 kW $\qquad P_{LL} = P_1 \times \left[0{,}025 - 0{,}005 \log 10 \left(\frac{P_2}{1\ \text{kW}} \right) \right]$

for $P_2 \geq 10\ 000$ kW $\qquad P_{LL} = P_1 \times 0{,}005$

For other than rated loads, it shall be assumed that the additional load losses vary as the square of the primary current minus the square of the no-load current.

NOTE The curve does not represent an average but an upper envelope of a large number of measured values, and may in most cases yield greater additional load losses than 8.2.2.5.1 or 8.2.2.5.2.

8.2.2.5.4 From an Eh-star test

8.2.2.5.4.1 Determination of intermediate values

For each test point according to 6.4.5.5 calculate the values using the equations in Annex B.

8.2.2.5.4.2 Smoothing of the additional-load loss data

The additional-load loss data shall be smoothed by using the linear regression analysis (see Figure 10).

The losses shall be expressed as a function of the square of the negative sequence current $I_{i(2)}$ related to test current I_t according to 6.4.5.5:

$$P_{Lr} = A \cdot \left(\frac{I_{i(2)}}{I_t} \right)^2 + B$$

A and B shall be computed similar to the procedure described in 8.2.2.5.1.2.

When the slope constant A is established, the value of additional load losses for rated load shall be determined by using the equation $P_{LL} = A \times T^2$.

9 Determination of efficiency (synchronous machines)

9.1 Determination from direct measurement

9.1.1 Torque procedure

When tested according to 6.3.1 the efficiency is:

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

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;

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

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

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

9.1.2 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:

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

where

$$P_{\mathrm{T}} = \frac{1}{2}(P_1 - P_2) + P_{1\mathrm{E}}\ ;\ P_{1\mathrm{E}} = \frac{1}{2}\left(P_{1\mathrm{E,M}} + P_{1\mathrm{E,G}}\right)$$

P_1 and P_2 are according to 6.3.2;

$P_{1\mathrm{E}}$ is according to 6.2 using 3.4.3.4.

9.2 Determination from indirect measurement

9.2.1 Total losses

9.2.1.1 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

$$\eta = 1 - \frac{P_{\mathrm{T}}}{P_{\mathrm{M}} + P_{1\mathrm{E}}}$$

where

P_{M} is the power absorbed at the terminals of the machine acting as a motor (excluding excitation power) according to 6.4.1.1;

P_{T} is the total losses, defined as half the total absorbed;

$P_{1\mathrm{E}}$ is the excitation power supplied by a separate source, for synchronous machines measured according to 6.4.1.1.4.

$$P_{\mathrm{T}} = \frac{1}{2}P_1 + P_{1\mathrm{E}};\ P_{1\mathrm{E}} = \frac{1}{2}\left(P_{1\mathrm{E,M}} + P_{1\mathrm{E,G}}\right)$$

9.2.1.2 Zero power factor procedure

For each desired load point, determine the efficiency with the measured values from 6.4.1.2 as follows:

$$\eta = 1 - \frac{P_{\mathrm{T}}}{P_1 + P_{1\mathrm{E}}}$$

where

$P_1 = \sqrt{3} \times U_{\mathrm{N}} \times I \cos\varphi_{\mathrm{N}}$ is the power absorbed at the armature winding terminals in rated operation;

P_{T} is the total losses, including excitation losses.

The total losses are:

a) for machines with exciter type c) and d) (see 3.4.3.3):

$$P_T = P_{1,zpf} + \Delta P_{fe} + P_e\,;$$

P_e shall be determined according to 6.2, applying the following temperature correction for the excitation winding resistance:

$$R_e = R_{e,0} \times \frac{235 + \theta_e}{235 + \theta_0}; \quad \theta_e = 25 + \left(\theta_w - \theta_c\right)\left(\frac{I_e}{I_{e,zpf}}\right)^2$$

where

I_e	is the excitation winding current determined as described in IEC 60034-4 (see also 6.4.1.2);
$P_{i,zpf}$	is equal to P_1 according to 6.4.1.2;
R_e	is the excitation winding resistance, temperature-corrected for the desired load;
$R_{e,0}$	is the cold winding resistance at temperature θ_0;
$I_{e,zpf}$	is the excitation winding current from the zero power factor test;
θ_w	is the excitation winding temperature of the zpf-test;
θ_c	is the reference coolant temperature of the zpf-test;
θ_e	is the excitation winding temperature-corrected to I_e;
ΔP_{fe}	is given below.

b) for machines with exciters type a) and b) (see 3.4.3.3):

P_e,P_{Ed} and P_{1E} are as defined in 6.2 from a test in 6.4.3.3 for the excitation winding current of the desired load, determined according to IEC 60034-4 (see also 6.4.1.2):

$$P_T = P_{1,zpf} + P_{1E,zpf} + \Delta P_{fe} + P_e$$

$$P_e = P_f + P_{Ed} - P_{f,zpf} - P_{Ed,zpf}$$

where

$P_{1,zpf}$, $P_{f,zpf}$ and $P_{1E,zpf}$	are measured values from the test in 6.4.1.2;
P_f	is determined as for separately-excited machines;
P_{Ed}, $P_{Ed,zpf}$	are determined from a test in 6.4.3.3 for I_e, R_e and $I_{e,zpf}, R_{e,zpf}$;
ΔP_{fe}	is determined from the iron loss-voltage curve (see 6.4.2.3), and is the difference of the values at voltages equal to the e.m.f. for the desired load and the e.m.f. of the zero power-factor test.

NOTE The equations are expressed for motor operation.

9.2.2 Summation of separate losses

9.2.2.1 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 9.2.2.2.

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.

9.2.2.2 Total losses

The total losses including excitation circuit losses are:

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

where

- P_k is according to 9.2.2.3;
- P_s is according to 9.2.2.5;
- P_{LL} is according to 9.2.2.6;
- P_e is according to 9.2.2.4.

9.2.2.3 Constant losses

9.2.2.3.1 General

For each value of voltage recorded in 6.4.2.3, determine the constant losses:

$$P_k = P_0 - P_s$$

where

$P_s = 1,5 \times {I_0}^2 \times R_{1l,0}$

P_0, I_0 and $R_{1l,0}$ are according to 6.4.2.3.

For machines with brushless exciters, excitation losses shall also be subtracted as follows:

$$P_k = P_0 - P_s - P_{f,0} - P_{Ed} + P_{1E}$$

where

$P_{f,0}$ is the excitation winding losses at no-load;
P_{Ed} is the exciter losses according to 6.4.3.3 corresponding to U_e and I_e of the test point;
P_{1E} is the power according to 6.2 corresponding to U_e and I_e of the test point.

9.2.2.3.2 Friction and windage losses

From the no-load test points (see 6.4.2.3), use all 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 values may be used for each of the load points.

9.2.2.3.3 Iron losses

For each of the values of voltage (see 6.4.2.3) develop a curve of constant losses against voltage. Subtract from this value the windage and friction losses to determine the iron losses.

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

9.2.2.4 Excitation circuit losses

9.2.2.4.1 General

For each load point, determine the excitation losses:

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

P_{Ed} and P_f are according to 9.2.2.4.2 and 9.2.2.4.3, respectively.

P_b is according to 9.2.2.4.4 when brushes are used.

9.2.2.4.2 From load test

P_f is the excitation winding loss according to 6.4.3.1.

P_{Ed} is the exciter loss according to 6.4.3.3:

$$P_{Ed} = 2\pi n\left(T_E - T_{E,0}\right) + P_{1E} - P_f$$

9.2.2.4.3 Without load test

P_f is the excitation winding loss according to 6.4.3.2.

P_{Ed} is the exciter loss according to 6.4.3.3.

In the case of separately excited synchronous machines, the excitation winding losss P_f is the product of U_e, I_e, diminished by the brush losses P_b according to 9.2.2.4.4.

9.2.2.4.4 Electrical losses in brushes

Determine brush losses from an assigned voltage drop per brush of each of the two polarities:

$$P_b = 2 \times U_b \times I_e$$

where

I_e is according to load test 6.4.3.1 or determined by calculation as in 6.4.3.2;

U_b is the voltage drop per brush of each of the two polarities depending on brush type:

1,0 V for carbon, electrographitic or graphite:

0,3 V for metal-carbon.

9.2.2.5 Load losses

9.2.2.5.1 Determination from a load test

At each of the load points determine the stator-winding losses:

$$P_s = 1,5 \times I^2 \times R_{ll}$$

where

I is according to 6.4.4.1;

R_{ll} is according to 6.4.4.1, corrected to 25 °C primary reference coolant temperature.

9.2.2.5.2 Determination without load test

Determine the stator winding losses:

$$P_s = 1,5 \times I^2 \times R_{ll}$$

where

I is the estimated stator current for the desired load point;

R_{ll} is the measured winding resistance referred to the reference temperature of 5.7.2.

9.2.2.6 Additional load losses P_{LL}

9.2.2.6.1 From test with coupled machine

The additional load losses at rated current result from the absorbed power of the short-circuit test in 6.4.5.6.1 diminished by the friction and windage losses P_{fw} according to 9.2.2.3.2 and the load loss at rated current according to 9.2.2.5.1 or 9.2.2.5.2.

$$P_{LL,N} = 2\pi nT - P_{fw} - P_s$$

In the case of a machine with brushless excitation, the excitation winding and the exciter loss part supplied by the driving machine shall additionally be subtracted:

$$P_{LL,N} = 2\pi nT + P_{1E} - P_{fw} - P_s - P_f - P_{Ed}$$

where

P_f is according to 6.2;

P_{Ed} is the exciter losses according to 6.4.3.3.

For other load points the additional losses result from

$$P_{\mathrm{LL}} = P_{\mathrm{LL,N}} \times \left(\frac{I}{I_{\mathrm{N}}} \right)^2$$

9.2.2.6.2 From test with uncoupled machine

The additional-load losses shall be determined from the uncoupled test 6.4.5.6.2.

In order to determine additional losses at any armature current, the constant losses P_{k} according to 9.2.2.3 and load losses P_{s} according to 9.2.2.5.1 at any armature current shall be subtracted from the power input at each armature current taken in test 6.4.5.6.2.

Annex A
(normative)

Correction of dynamometer torque readings

NOTE This correction method also applies if any bearing is interposed between the torque measuring device and the motor shaft.

A.1 Correction from test with motor running at no-load

A.1.1 Dynamometer coupled

Run the motor at rated voltage and frequency, coupled to the dynamometer with the dynamometer de-energized.

Measure and record $P_{d,0}$, $I_{d,0}$, n, $T_{d,0}$ and $R_{d,0}$ or temperature θ (with R derived from the test measurements).

Determine slip (s) and

$$P_d = \left(I^2R\right)_{d,0} = 1,5 \times I_{d,0}^2 \times R_{d,0}$$

A.1.2 Motor uncoupled

Run the motor at rated voltage and frequency, uncoupled from the dynamometer.

Measure and record P_0, I_0 and R_0 or temperature θ (with R derived from the test measurements).

Determine:

$$P_s = \left(I^2R\right)_0 = 1,5 \times I_0^2 \times R_0$$

A.1.3 Dynamometer correction

Determine dynamometer torque correction T_c in N·m as follows:

$$T_c = \frac{\left(P_{d,0} - P_d - P_{fe}\right)\left(1-s\right) - \left(P_0 - P_s - P_{fe}\right)}{2\pi n} - T_{d,0}$$

where

n, $P_{d,0}$, P_d, s and $T_{d,0}$ are according to A.1.1;

P_0 and P_s are according to A.1.2;

P_{fe} is according to 8.2.2.3.3.

NOTE In practice, T_d is mostly compensated by calibration of the dynamometer, so that the dynamometer reading is 0,0 when the shaft torque is 0,0.

A.2 Correction from test with uncoupled motor

Uncouple the tested motor; the coupling device shall be coupled with the shaft of the dynamometer. Run the dynamometer as a motor, with external cooling, if any. The dynamometer correction T_c is equal to the measured torque, with speeds n the same as under load at each of the load points.

NOTE This test is not possible with loading devices acting as a mechanical load only, for example eddy current dynamometers.

Annex B
(normative)

Calculation of values for the Eh-star method

Determine the following complex voltages and currents from the test results:

$$\underline{U}_{\mathrm{UV}} = U_{\mathrm{UV}}$$

$$U'_{\mathrm{WU}} = \frac{U_{\mathrm{VW}}^2 - U_{\mathrm{WU}}^2 - U_{\mathrm{UV}}^2}{2 \cdot U_{\mathrm{UV}}}$$

$$U''_{\mathrm{WU}} = \sqrt{U_{\mathrm{WU}}^2 - U'^2_{\mathrm{WU}}}$$

$$U'_{\mathrm{VW}} = -U_{\mathrm{UV}} - U'_{\mathrm{WU}}$$

$$U''_{\mathrm{VW}} = -U''_{\mathrm{WU}}$$

$$I'_{\mathrm{V}} = -\frac{(P_{\mathrm{UV}} - P_{\mathrm{VW}}) + U_{\mathrm{WU}} \cdot I_{\mathrm{W}}}{U_{\mathrm{UV}}}$$

NOTE In the above equation, it is assumed that current I_{W} is in phase with voltage U_{WU}. In the case where the impedance of the resistor contains a noticeable reactive component, use the following formula

$$I'_{\mathrm{V}} = -\frac{(P_{\mathrm{UV}} - P_{\mathrm{VW}}) + R_{\mathrm{eh}} \cdot I_{\mathrm{W}}^2}{U_{\mathrm{UV}}}$$

where R_{eh} is the measured value of the resistive component.

$$I''_{\mathrm{V}} = \sqrt{I_{\mathrm{V}}^2 - I'^2_{\mathrm{V}}}$$

$$k_1 = \frac{1}{2 \cdot I_{\mathrm{V}}^2} \cdot \left(I_{\mathrm{W}}^2 - I_{\mathrm{U}}^2 - I_{\mathrm{V}}^2\right)$$

$$I'_{\mathrm{U}} = k_1 \cdot I'_{\mathrm{V}} + \sqrt{(k_1^2 - \frac{I_{\mathrm{U}}^2}{I_{\mathrm{V}}^2})(I'^2_{\mathrm{V}} - I_{\mathrm{V}}^2)}$$

$$I''_{\mathrm{U}} = \frac{k_1 I_{\mathrm{V}}^2 - I'_{\mathrm{U}} \cdot I'_{\mathrm{V}}}{I''_{\mathrm{V}}}$$

$$I'_{\mathrm{W}} = -I'_{\mathrm{U}} - I'_{\mathrm{V}}$$

$$I''_{\mathrm{W}} = -I''_{\mathrm{U}} - I''_{\mathrm{V}}$$

Determine the inner line-to-line voltages from the complex line-to-line voltages and currents:

$$\underline{U}_{\mathrm{iUV}} = \underline{U}_{\mathrm{UV}} + \frac{R_{\mathrm{VW}}}{2} \cdot \left(\underline{I}_{\mathrm{V}} - \underline{I}_{\mathrm{U}}\right)$$

$$\underline{U}_{\mathrm{iVW}} = \underline{U}_{\mathrm{VW}} + \frac{R_{\mathrm{VW}}}{2} \cdot \left(\underline{I}_{\mathrm{W}} - \underline{I}_{\mathrm{V}}\right)$$

$$\underline{U}_{\mathrm{iWU}} = \underline{U}_{\mathrm{WU}} + \frac{R_{\mathrm{VW}}}{2} \cdot \left(\underline{I}_{\mathrm{U}} - \underline{I}_{\mathrm{W}}\right)$$

Separate into positive and negative sequence line-to-line components $(\underline{a} = e^{j2\pi/3})$:

$$\underline{U}_{\mathrm{iLL(1)}} = \frac{1}{3} \cdot \left(\underline{U}_{\mathrm{iUV}} + \underline{a} \cdot \underline{U}_{\mathrm{iVW}} + \underline{a}^2 \cdot \underline{U}_{\mathrm{iWU}} \right)$$

$$\underline{U}_{\mathrm{iLL(2)}} = \frac{1}{3} \cdot \left(\underline{U}_{\mathrm{iUV}} + \underline{a}^2 \cdot \underline{U}_{\mathrm{iVW}} + \underline{a} \cdot \underline{U}_{\mathrm{iWU}} \right)$$

Determine the positive and negative sequence components of the inner phase voltage $\underline{U}_{\mathrm{i}}$:

$$\underline{U}_{\mathrm{i(1)}} = \frac{1}{\sqrt{3}} \cdot e^{-\mathrm{j}\frac{\pi}{6}} \cdot \underline{U}_{\mathrm{iLL(1)}}$$

$$\underline{U}_{\mathrm{i(2)}} = \frac{1}{\sqrt{3}} \cdot e^{\mathrm{j}\frac{\pi}{6}} \cdot \underline{U}_{\mathrm{iLL(2)}}$$

Determine the asymmetrical inner phase voltages:

$$\underline{U}_{\mathrm{iU}} = \underline{U}_{\mathrm{i(1)}} + \underline{U}_{\mathrm{i(2)}}$$

$$\underline{U}_{\mathrm{iV}} = \underline{a}^2 \cdot \underline{U}_{\mathrm{i(1)}} + \underline{a} \cdot \underline{U}_{\mathrm{i(2)}}$$

$$\underline{U}_{\mathrm{iW}} = \underline{a} \cdot \underline{U}_{\mathrm{i(1)}} + \underline{a}^2 \cdot \underline{U}_{\mathrm{i(2)}}$$

Determine the iron loss resistance:

$$R_{\mathrm{fe}} = \frac{U_{\mathrm{t}}^2}{P_{\mathrm{fe}}}$$

where

U_{t} is according to 6.4.5.5

P_{fe} is according to 8.2.2.3.3

$$\underline{I}_{\mathrm{feU}} = \frac{\underline{U}_{\mathrm{iU}}}{R_{\mathrm{fe}}}$$

$$\underline{I}_{\mathrm{feV}} = \frac{\underline{U}_{\mathrm{iV}}}{R_{\mathrm{fe}}}$$

$$\underline{I}_{\mathrm{feW}} = \frac{\underline{U}_{\mathrm{iW}}}{R_{\mathrm{fe}}}$$

Determine the inner phase currents:

$$\underline{I}_{\mathrm{iU}} = \underline{I}_{\mathrm{U}} - \underline{I}_{\mathrm{feU}}$$

$$\underline{I}_{\mathrm{iV}} = \underline{I}_{\mathrm{V}} - \underline{I}_{\mathrm{feV}}$$

$$\underline{I}_{\mathrm{iW}} = \underline{I}_{\mathrm{W}} - \underline{I}_{\mathrm{feW}}$$

Determine the positive and negative sequence components of the inner phase currents:

$$\underline{I}_{\mathrm{i(1)}} = \frac{1}{3} \cdot \left(\underline{I}_{\mathrm{iU}} + \underline{a} \cdot \underline{I}_{\mathrm{iV}} + \underline{a}^2 \cdot \underline{I}_{\mathrm{iW}} \right)$$

$$\underline{I}_{\mathrm{i(2)}} = \frac{1}{3} \cdot \left(\underline{I}_{\mathrm{iU}} + \underline{a}^2 \cdot \underline{I}_{\mathrm{iV}} + \underline{a} \cdot \underline{I}_{\mathrm{iW}} \right)$$

The absolute values of the positive sequence current $I_{\mathrm{i(1)}}$ shall be less than 30 % of the absolute value of the negative sequence current $I_{\mathrm{i(2)}}$ in order to achieve accurate results. If this condition is not met, the test shall be repeated by a different value of R_{eh}.

Determine the airgap power:

$$P_{\delta(1)} = 3 \cdot \left(U'_{i(1)} \cdot I'_{i(1)} + U''_{i(1)} \cdot I''_{i(1)} \right)$$
$$P_{\delta(2)} = 3 \cdot \left(U'_{i(2)} \cdot I'_{i(2)} + U''_{i(2)} \cdot I''_{i(2)} \right)$$

Determine the additional load losses:

$$P_{\mathrm{Lr}} = k \cdot \left[(1\text{-s}) \cdot \left(P_{\delta(1)} - P_{\delta(2)} \right) - P_{\mathrm{fw}} \right]$$
$$\text{where} \quad k = \frac{1}{1 + \left(I_{\mathrm{i}(1)} / I_{\mathrm{i}(2)} \right)^2}$$

Annex C
(informative)

Types of excitation systems

The types of excitation systems considered for determination of the exciter losses are:

a) shaft driven exciter

A d.c. or a.c. exciter machine is driven by the shaft of the main unit, directly or through a gear. When the main unit is a synchronous machine the excitation power is supplied to the excitation winding via slip-ring and brushes.

b) brushless exciter

An a.c. exciter coupled to a synchronous main unit supplies the field winding directly via rotating rectifiers, avoiding slip-rings and brushes. The exciter can be a synchronous generator or an induction machine.

Excitation power of a synchronous exciter is derived either from a directly coupled a.c. pilot exciter with permanent magnet excitation, or from an auxiliary (secondary) winding in the main unit stator slots (same as in e)), or from a static supply.

An induction exciter is connected to a variable a.c. voltage supply.

c) separate rotating exciter

A d.c. or a.c. generator as part of a separate motor generator set supplies the excitation current to the field winding of the main unit.

d) static excitation system (static exciter)

The excitation power is supplied to the field winding of the main unit by a static source such as batteries or a static power converter-fed from a separate source.

e) excitation from auxiliary winding (auxiliary winding exciter)

The excitation power for an a.c. generator is provided by an auxiliary (secondary) winding in the main unit stator slots, utilizing fundamental or harmonic flux, and supplied to the field winding via rectifiers, slip-rings and brushes.

Annex D
(normative)

Other test methods

D.1 Purpose

The following test procedures from IEC 60034-2:1972 with its amendment 1:1995 (defining IEC 60034-2A:1974 as Clause 17) and its amendment 2:1996 are not included in the present IEC 60034-2-1:

Calibrated-machine test

Retardation test

Calorimetric method

These methods are considered to be applicable mainly for large machines where the facility cost for other methods is not considered economical. They will be included in IEC 60034-2-2 which is under consideration. This annex makes provisions to retain these methods as normative in the meantime. Following the publication of IEC 60034-2-2 covering the revision of these methods, this annex will be withdrawn.

D.2 Calibrated-machine test

D.2.1 Definition

A test in which the mechanical input or output of an electrical machine is calculated from the electrical output or input of a calibrated machine mechanically coupled to the machine on test.

D.2.2 Method

The machine of which the losses are to be measured is separated from the network. uncoupled from its driving motor if necessary, and driven at its rated speed by a calibrated motor, that is by an electric motor of which the losses have been previously determined with great accuracy, so that it is possible to determine the mechanical power which it furnishes at its shaft, knowing the electric power which it absorbs and its speed of rotation. The mechanical power transmitted by the calibrated motor to the shaft of the machine under test is a measure of the losses of this latter machine for the working conditions under which the test is made. In this method. the machine tested may be on no-load, excited or not excited, with or without brushes or short-circuited, which enables categories of losses to be separated.

As an alternative, the calibrated motor may be replaced by a dynamometer or by any other motor driving the machine under test through an appropriate torsionmeter, which enables the torque transmitted to the machine under test to be known, and hence the mechanical power absorbed by this latter machine.

D.2.3 Determination of efficiency

When the machine is running in accordance with D.2.2 at rated conditions of speed, voltage and current, the efficiency is taken as the ratio of output to input.

The test shall be made as nearly as possible at the temperature attained in operation at the end of the time specified in the rating. No winding temperature correction shall be made.

NOTE Clause D.2 repeats, technically unchanged, 4.4 and 13 of IEC 60034-2:1972; as well as 7.3.2, 9.3.2 and 11.3.2 of IEC 60034-2, amendment 1:1995.

D.3 Retardation method

D.3.1 Definition

A test method in which the losses in a machine are deduced from the rate of deceleration of the machine when only these loses are present.

A retardation method can be used for determining the separate losses of rotating electrical machines.

The methods of determination of losses covered by this clause are basically intended for large synchronous machines, but the principles used can also be applied to other machines (a.c. induction and d.c. machines, exhibiting mainly an appreciable rotational inertia) using the appropriate losses for such machines.

The retardation method is used to determine:

– the sum of the friction loss and windage loss ("mechanical losses") in machines of all types;
– the sum of losses in active iron and additional open-circuit losses in d.c. and synchronous machines;
– the sum of I^2R losses in an operating winding and additional load losses ("short-circuit losses") in synchronous machines.

D.3.2 General

D.3.2.1 Fundamentals

The total of the losses P_t which retard the machine is proportional to the product of the speed to which these losses correspond and the deceleration at this speed:

$$P_t = -C\,n\frac{dn}{dt}$$

where

P_t is the total of the losses during the retardation test.

When n is expressed in rev/min and P_t is given in kW, then the retardation constant C is:

$$C = \frac{4\pi^2\,J}{60^2\,10^3} = 10{,}97 \times 10^{-6}\,J$$

where

J is the moment of inertia, in kg·m^2.

The deceleration dn/dt can be obtained either directly, using an accelerometer, or indirectly, by one of the methods given in D.3.2.2, D.3.2.3 and D.3.2.4 below.

D.3.2.2 Method of the chord

This requires the measurement of the time interval (t_2 − t_1) during which the speed of the tested machine changes from n_N·(1 + δ) to n_N·(1 − δ), see Figure D.1. The ratio of speed interval 2 δ n_N to time interval $t_2 - t_1$ is approximately the deceleration at rated speed:

$$\frac{2\delta\,n_N}{n_2 - n_1} \approx -\left.\frac{dn}{dt}\right|_{n = n_N}$$

where

δ is the per unit deviation of rotational speed from rated speed.

The value of δ shall not be greater than 0,1 and may have to be less than this depending on the characteristics of the machine.

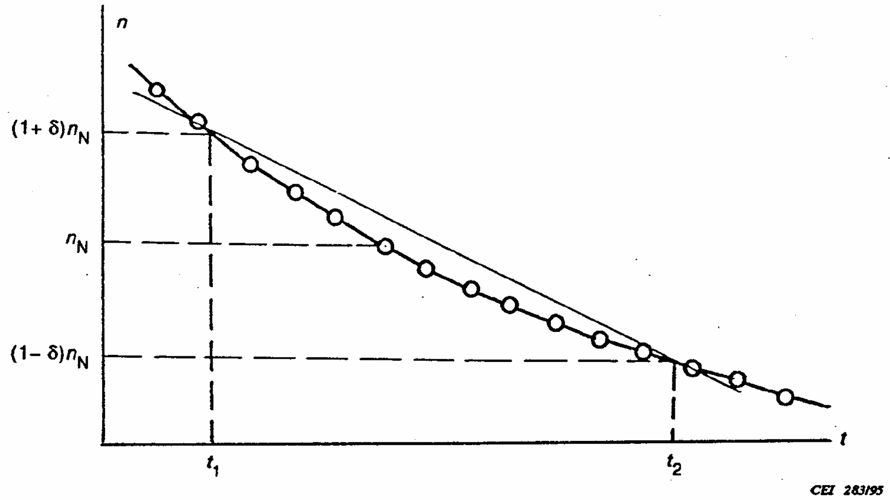

Figure D.1 – Method of the chord

D.3.2.3 Method of the limiting secant

This is a variant of the method of the chord and is intended to be applied in cases when the speed of rotation cannot be increased above the rated value. The instant of time when the speed of rotation is of the rated value n_N is marked as t_1, and the time instants at which the speed of rotation acquires the values of $n_N \cdot (1 - \delta)$ are marked as t_2. The deviation δ is successively decreased, and the time derivative of the speed of rotation is the limit of the tangent of the angle made by the line passing through the points t_1 and t_2 with the time axis, as δ approaches zero, see Figure D.2.

$$\lim_{\delta \to 0} \frac{\delta\, n_N}{t_2 - t_1} \approx -\left.\frac{dn}{dt}\right|_{n = n_N}$$

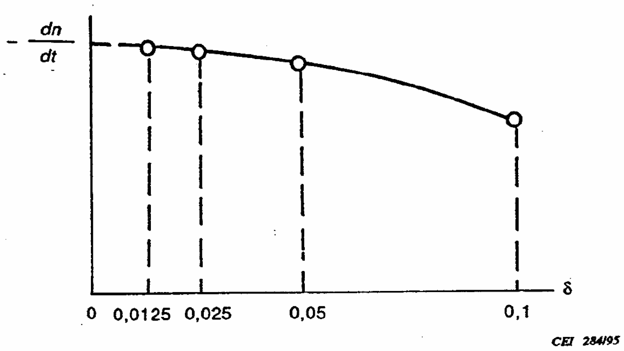

Figure D.2 – Method of the limiting secant

D.3.2.4 Method of the average speed of rotation

If t_1, t_2 and t_3 represent the successively recorded time readings, the shaft making N complete revolutions within the time interval between any two subsequent readings, then the average values of speed during the time intervals shall be:

$$\bar{n}_{12} = \frac{60\,N}{t_2 - t_1} \quad \text{and} \quad \bar{n}_{23} = \frac{60\,N}{t_3 - t_2}$$

and the deceleration of the shaft at an intermediate moment of time t_2 is

$$\frac{\mathrm{d}n}{\mathrm{d}t} = 2\frac{\bar{n}_{23} - \bar{n}_{12}}{t_3 - t_1}$$

Calculated values of deceleration are plotted against the average values of speed of rotation. The value of deceleration at the rated speed of rotation is determined from the curve.

D.3.3 Composition of retardation tests

D.3.3.1 Composition of tests with known moment of inertia

When the moment of inertia of a machine rotating part is known by measurement or by design, then for a d.c. machine two basic retardation tests are sufficient: the machine running unexcited and the machine running open-circuited, excited at rated voltage at rated speed. For a synchronous machine a third retardation test should be made with the armature winding being short-circuited and the excitation set to give the rated armature current.

The first test gives the mechanical (friction and windage) losses P_{fw} of the tested machine from the formula:

$$P_{\mathrm{fw}} = -C\,n_{\mathrm{N}}\,\frac{\mathrm{d}n}{\mathrm{d}t}\bigg|1$$

The second test gives the total of mechanical losses P_{fw} and iron losses P_{fe} from the formula:

$$P_{\mathrm{fw}} + P_{fe} = -C\,n_{\mathrm{N}}\,\frac{\mathrm{d}n}{\mathrm{d}t}\bigg|2$$

The third test gives the sum of mechanical losses P_{fw} and short-circuit losses P_{k} from the formula:

$$P_{\mathrm{fw}} + P_{\mathrm{k}} = -C\,n_{\mathrm{N}}\,\frac{\mathrm{d}n}{\mathrm{d}t}\bigg|3$$

In the above equations

$$\frac{\mathrm{d}n}{\mathrm{d}t}\bigg|1,\ \frac{\mathrm{d}n}{\mathrm{d}t}\bigg|2,\ \frac{\mathrm{d}n}{\mathrm{d}t}\bigg|3$$

are the values of speed derivative in time in the first, second and third test, respectively.

The iron losses are determined as the difference of the losses measured in the second and first tests.

The sum of the I^2R losses and the additional losses in the armature circuit are determined as the difference of losses measured in the third and first test. Separation of this sum into components, if required, is done by subtracting from it the I^2R losses in the armature circuit calculated from the armature circuit resistance corresponding to the test temperature. For this purpose, the winding temperature shall be deduced by the appropriate method of temperature measurement directly after each retardation test with the armature circuit being short-circuited.

D.3.3.2 Composition of tests with unknown moment of inertia

When the moment of inertia of a machine rotating part is not known, or the machine is coupled mechanically to other rotating parts, for example a turbine, whose inertia is not known, then some additional tests shall be carried out to determine the retardation constant C.

In the instance where there is a possibility to run the tested machine as an unloaded motor from a power supply of the proper voltage, number of phases and frequency (in the case of a.c. machines), and the power supplied to the tested machine can be measured, (equal to the sum of the mechanical losses P_{fw} and iron losses P_{fe} , as the armature circuit I^2R losses are usually ignored), then the retardation constant C is determined from the formula:

$$C = \frac{P_{fw} + P_{fe}}{n_N \left. \frac{dn}{dt} \right| 2}$$

If the measurement of power is difficult because of frequency oscillations of the power supply, then as an alternative the energy supplied to the tested machine may be measured with an integrating meter. For this purpose, it is necessary to run the machine as a motor for some time at constant supply conditions.

In the instance where there is no possibility of running the tested machine as an unloaded motor, then, in addition to the three retardation tests considered in D.3.3.1, one more retardation test shall be conducted. The tested machine in this case is slowed down by any losses P which can be measured and are of the same order as the expected iron losses P_{fe} and short-circuit losses P_k. For this purpose, the open-circuit or short-circuit losses of a connected transformer can be used, which are separately measured. Alternatively, if an exciter or auxiliary generator mounted on the tested machine shaft is available, its load with a ballast resistance may be used.

If the tested machine is slowed down by the transformer open-circuit losses, and the short-circuit losses according to the transformer open-circuit current are ignored, then

$$P_{fw} + P_{fe} + P = -C\, n_N \left. \frac{dn}{dt} \right| 4 \quad ;$$

hence

$$C = \frac{P}{n_N \left\{ \left. \frac{dn}{dt} \right| 4 - \left. \frac{dn}{dt} \right| 2 \right\}}$$

When the tested machine is slowed down by the transformer short-circuit losses, usually the iron losses corresponding to magnetic flux in the short-circuited transformer are ignored. Hence

$$P_{fw} + P_k + P = -C\, n_N \left. \frac{dn}{dt} \right| 5 \quad ;$$

and

$$C = \frac{P}{n_N \left\{ \left. \frac{dn}{dt} \right| 5 - \left. \frac{dn}{dt} \right| 3 \right\}}$$

When the tested machine is slowed down by an exciter or auxiliary generator loaded with a ballast resistance, the retardation losses consist only of the tested machine mechanical losses P_{fw} and the measured load P (with allowance for efficiency of the load machine that can be determined by calculations). Hence:

$$P_{fw} + P = -C\, n_N \left. \frac{dn}{dt} \right| 6 \quad ;$$

so that

$$C = \frac{P}{n_{\mathrm{N}}\left\{\frac{\mathrm{d}n}{\mathrm{d}t}\middle|6 - \frac{\mathrm{d}n}{\mathrm{d}t}\middle|1\right\}}$$

D.3.4 Retardation test procedure

D.3.4.1 State of a tested machine during retardation tests

A tested machine shall be completely assembled as for normal operation. The bearings shall be "run in" prior to the test. The air temperature shall be adjusted wherever possible to the normal temperature at which the windage loss measurement is required by throttling the air coolant flow. The bearing temperatures shall be adjusted to the normal temperature at which the bearings operate with rated load, by adjusting the coolant flow.

D.3.4.2 Tested machine coupled with other mechanisms

When possible, the tested machine shall be uncoupled from other rotating parts. If the machine cannot be uncoupled, all possible steps shall be taken to reduce the mechanical losses in other rotating parts, for example by partial dismantling or in the case of a water turbine, by removing water from the runner chamber. Means shall also be taken to eliminate the possibility of water flowing from the upstream side and from drawing water by the rotating runner from the downstream side. Rotation of the runner in the air produces windage losses which can be stated experimentally or from calculations by agreement between manufacturer and purchaser.

D.3.4.3 Rotation of a tested machine

In some cases, the tested machine can be driven by its normal prime mover, for example by Pelton turbine where the water supply to the runner can be cut off instantly. However, the tested machine is usually running as a motor on no-load, fed from a separate source with a wide range of variable speeds. In all cases, the excitation shall be obtained from a separate source with a rapid and precise voltage control. The excitation from the inherent mechanically-coupled exciter is not recommended in principle, but may be permitted in those cases when the value of the deviation of speed δ is relatively small, for example if it does not exceed 0,05. In all these cases, the losses in exciters coupled to the shaft of the tested machine shall be taken into account.

D.3.4.4 Procedure performed prior to starting the tests

Each test begins with the tested machine being rapidly accelerated to a speed above $n_{\mathrm{N}}\cdot(1+\delta)$ so that during deceleration to this speed the machine can be placed in the required condition, namely:

– the machine is disconnected from a supply source;
– in the case of retardation by only mechanical loss, the machine field is suppressed;
– in the case of retardation by the sum of the mechanical loss and short-circuit losses, the machine field is suppressed, the armature terminals are short-circuited and the machine is re-excited to the preset short-circuit current;
– in the case of retardation by the transformer losses after field suppression, the tested machine is connected to the transformer previously set to a certain state (at no-load or short-circuited) and excited to the preset values of current or open-circuit voltage;
– in the case of retardation by the exciter load losses or auxiliary generator mounted on the machine shaft, the tested machine field is suppressed and the specified load is set simultaneously.

In all cases described above, a sufficient time delay shall separate the switching off of the supply and starting the measurements to allow electromagnetic transients to decay.

In the case of retardation by the sum of mechanical and iron losses or by the open-circuit losses of a supply transformer, no procedures are required after the machine is disconnected from the supply if the tested machine excitation corresponds to the preset open-circuit voltage, and,in the case of a synchronous machine, at rated speed and unity power factor.

D.3.4.5 Procedures during retardation

The readings of all instruments used for each test (field current ammeter, open-circuit voltage voltmeter, short-circuit current ammeter) and of all instruments required to measure the power in additional retardation tests when the moment of inertia J is not known, shall be taken at the instant when the tested machine passes through rated speed; no readings at this instant are required in the case of an unexcited retardation test.

The measured values of open-circuit voltage or short-circuit current shall not differ from the preset values by more than ±2 %. The calculated final value of the speed derivative in time for each of the tests shall be adjusted proportionally by the ratio of the square of the preset value to the measured value.

D.3.4.6 Program of retardation tests

The retardation tests shall be conducted as a series without interruption, whenever possible. It is recommended that the series start and finish with some retardation tests of an unexcited machine. If for any reason, the test series is not conducted in a continuous manner, then it is recommended that each subsequent series of tests start and finish with some unexcited retardation tests.

Tests may be either repeated several times at the same preset values of open-circuit voltage or short-circuit current, for example at rated values, or at various values within limits of the order of 95 % to 105 % of the rated values. In the first case, the arithmetic mean values obtained from all measurements are assumed to be the real measured value of each type of loss. In the second case, the values are plotted on a curve as a function of voltage or current. Real measured values are assumed to be those occurring at the points of intersection of the preset values of voltage or current as read from the curves.

Additional retardation tests, when the moment of inertia of the tested machine is not known, shall be conducted at the same values of voltage or current as those obtained with the winding open- or short-circuited. If this is not possible, the respective values shall be determined from curves as indicated above.

D.3.5 Taking of measurements

D.3.5.1 Methods of measurements

The measurements taken during retardation tests are aimed at obtaining the required value of the speed derivative in time and may be performed by one of the three methods:

a) accelerometric - direct measurement of deceleration with time:

$$\frac{dn}{dt} = f(t);$$

b) tachometric - by determining the dependence of speed with time:

$$n = f(t);$$

c) chronographic - by determining the dependence of angular displacement of the tested machine shaft with time:

$$\gamma = f(t).$$

For all cases, recording measuring instruments may be used both with continuous and with discrete recording of measured values and time.

D.3.5.2 Accelerometric method

The dependence of speed on time for large machines having a complex ventilation route may not be regular. As a consequence of this, the instantaneous values of deceleration during retardation at the moment of passing through rated speed may be random. Therefore, true values of the speed derivative may be determined by plotting measured decelerations versus time or speed and using a suitable curve fitting or correlation technique.

D.3.5.3 Tachometric method

A plot of speed versus time is obtained from the results of measurements. On this plot, the time instants are defined at which the speed acquired the values indicated for the chord or limiting secant method. The differences between the times at the lower and upper limits of speed are used to calculate the decelerations.

If there is an exciter or any other electrical machine on the tested machine shaft, it can be used as a tachogenerator, provided that the voltage signal does not pulsate with the speed of rotation of the tested machine. The excitation shall be supplied from a stable d.c. source, such as a separate storage battery.

If the voltage signal does pulsate with the speed of rotation or when there is no such tachogenerator on the tested machine, a coupled d.c. machine may be used. It can be driven from the shaft of the tested machine by a seamless belt or by other means to provide smooth rotation.

Readings of the speed may be made either in the exact time intervals, specified by the respective method, in which case there is no need for special recording of time or of signals from the tested machine shaft; in this case, the readings of time shall be taken concurrently with readings of speed. There is no need to take readings with each turn of the shaft; usually 30 to 40 readings during the whole test are quite sufficient.

With the availability of high-accuracy measuring instruments, the measurement of speed of rotation may be substituted by measurement of the instantaneous values of speed or of the period of the voltage of the tested machine or of any other a.c. machine situated on its shaft; it is not necessary that the number of pole pairs of both machines is equal.

D.3.5.4 Chronographic method

The time-counters used may be either visual indicators with continuous (non-stepwise) motion of the pointer, or digital indicators with printers (electrical or mechanical).

Time readings shall be taken according to the signals obtained from the tested machine shaft either with each complete revolution of the shaft or for a known number of revolutions.

NOTE If when using the tachometric method the speed of rotation is determined by signals from the tested machine shaft, then the time readings may be used both for tachometric and chronographic methods, thus providing a mutual check.

In some cases, when the unit has smooth deceleration characteristics, sufficient accuracy can be obtained by measuring the time for retardation between two speeds with the same difference to the rated speed

$$\frac{\mathrm{d}n}{\mathrm{d}t} = \frac{\Delta n}{\Delta t}$$

The stator voltage frequency provides the best means of determining the speed of a synchronous machine.

D.3.5.5 Measurement of losses in bearings

The losses in bearings and thrust bearings can be subtracted from the total sum of the mechanical losses, if required. These may be determined by the calorimetric method in accordance with IEC 60034-2A. If the tested machine uses direct-flow cooling of the bearings, these losses are distributed between the tested machine and any other coupled to it mechanically, such as 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 between manufacturer and purchaser.

NOTE Clause D.3 repeats, technically unchanged, 4.7 of IEC 60034-2:1972, and Clause 15 of IEC 60034-2, amendement 1:1995.

D.4 Calorimetric method

D.4.1 Definition

A test method in which the losses in a machine are deduced from the heat produced by them. The losses are calculated from the product of the amount of coolant and its temperature rise, and the heat dissipated in the surrounding media.

NOTE Subclause D.4.1 repeats 4.8 of IEC 60034-2:1972.

D.4.2 Method

In accordance with IEC 60034-2A 1974 (named Clause 17 in IEC 60034-2, amendement 1 1995).