

INTERNATIONAL STANDARD

NORME INTERNATIONALE

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

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



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INTERNATIONAL ELECTROTECHNICAL COMMISSION

ROTATING ELECTRICAL MACHINES –

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

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

This third edition cancels and replaces the second edition of IEC 60034-2-1 published in 2014. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

Harmonization of layout and requirements with IEC 60034-2-2 and IEC 60034-2-3.

The text of this International Standard is based on the following documents:

Draft	Report on voting
2/2165/FDIS	2/2177/RVD

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

The language used for the development of this International Standard is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications.

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

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

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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 document applies to DC machines and to AC synchronous and induction machines of all sizes within the scope of IEC 60034-1 rated for mains operation.

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

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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 60034-1:2022, *Rotating electrical machines – Part 1: Rating and performance*

IEC 60034-4-1:2018, *Rotating electrical machines – Part 4-1: Methods for determining electrically excited synchronous machine quantities from tests*

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

IEC 60034-29, *Rotating electrical machines – Part 29: Equivalent loading and superposition techniques – Indirect testing to determine temperature rise*

IEC 60034-30-1, *Rotating electrical machines – Part 30-1: Efficiency classes of line operated AC motors (IE code)*

IEC 60051(all parts), *Direct acting indicating analogue electrical measuring instruments and their accessories*

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

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 apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at <http://www.electropedia.org/>
- ISO Online browsing platform: available at <http://www.iso.org/obp>

3.1

efficiency

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

3.2

direct efficiency determination

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

3.3

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

3.4

indirect efficiency determination

method by which the 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

3.5

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

3.6

no-load test

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

3.7

zero power factor test

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

3.8

equivalent circuit method

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

3.9**test with rotor removed and reverse rotation test**

combined test on an induction machine 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 of the stator

3.10**short-circuit test**

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

3.11**locked rotor test**

test in which the rotor is locked to prevent rotation

3.12**Eh-star test**

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

3.13**losses****3.13.1****total losses**

P_T

difference between the input power and the output power, equivalent to the sum of the constant losses (see 3.13.2), the load losses (see 3.13.4), the additional load losses (see 3.13.5) and the excitation circuit losses (see 3.13.3)

3.13.2**constant losses**

P_c

losses incorporating the sum of windage, friction and iron losses

Note 1 to entry: Although these losses change with voltage and load, they are historically called “constant” losses and the name is retained in this document.

3.13.2.1**iron losses**

P_{fe}

losses in active iron and additional no-load losses in other magnetic and conductive parts

3.13.2.2**friction and windage losses**

P_{fw}

losses incorporating the sum of windage and friction

3.13.2.2.1**friction losses**

losses due to friction (bearings and brushes, if not lifted at rated conditions) not including any losses in a separate lubricating system

3.13.2.2.2

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 to entry: Losses in a separate ventilating system should be listed separately.

Note 2 to entry: For machines indirectly or directly cooled by hydrogen, see IEC 60034-1.

3.13.3

excitation circuit losses

3.13.3.1

excitation circuit losses

P_e

sum of the excitation winding losses (see 3.13.3.2), the exciter losses (see 3.13.3.3) and, for synchronous machines, electrical brush loss (see 3.13.3.5), if any

3.13.3.2

excitation winding losses

P_f

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

3.13.3.3

exciter losses

P_{Ed}

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

a) shaft driven exciter

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 3.13.3.2 plus (in the case of a synchronous machine) the electrical brush losses as per 3.13.3.5.

Note 1 to entry: If the exciter can be decoupled and tested separately its losses can be determined according to 7.1.3.2.1.5.

Note 2 to entry: 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

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.

Note 3 to entry: 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.

Note 4 to entry: If the exciter can be decoupled and tested separately, its losses can be determined according to 7.1.3.2.1.

c) separate rotating exciter

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 3.13.3.2 and 3.13.3.4. The exciter losses may be determined according to 7.1.3.2.1.

d) static excitation system

static exciter

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 3.13.3.2 and 3.13.3.4.

Note 5 to entry: 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

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.

Note 6 to entry: 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 (DC 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 B as applicable.

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

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

- for exciter types a) and b) the exciter excitation power (DC 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 3.13.3.3.

3.13.3.5**brush losses (excitation circuit)** P_b

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

3.13.4**load losses****3.13.4.1****load losses** P_L

sum of the winding (I^2R) losses (see 3.13.4.2) and the electrical brush losses (see 3.13.3.5), if any

3.13.4.2 winding losses

winding losses are I^2R losses:

- in the armature circuit of DC machines;
- in the stator and rotor windings of induction machines;
- in the armature and field windings of synchronous machines

3.13.4.3 brush losses

P_b

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

3.13.5 additional load losses

P_{LL}

losses produced in active iron and other magnetic and conductive parts by alternating stray fluxes when the machine is loaded; eddy current losses in winding conductors caused by load current-dependent flux pulsations and additional brush losses caused by commutation

Note 1 to entry: These losses do not include the additional no-load losses of 3.13.2.2.

3.13.6 short-circuit losses

P_{sc}

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

3.14 test quantities <polyphase AC machines>

3.14.1 terminal voltage

for polyphase AC machines, the arithmetic average of line voltages

3.14.2 line current

for polyphase AC machines, the arithmetic average of line currents

3.14.3 line-to-line resistance

for polyphase AC machines, the arithmetic average of resistances measured between each pair of terminals

Note 1 to entry: For Y-connected three-phase machines, the phase-resistance is 0,5 times the line-to-line resistance. For Δ -connected machines, the phase-resistance is 1,5 times the line-to-line resistance.

Note 2 to entry: In Clauses 6 and 7 explanations and formulae given are for three-phase machines, unless otherwise indicated.

3.14.4 temperature rise

is the machine temperature minus the cooling medium (coolant) temperature as defined by IEC 60034-1

4 Symbols and abbreviated terms

4.1 Symbols

$\cos \varphi$	is the power factor ¹
f	is the supply frequency, Hz
I	is the line current (average of all phases), 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_D	is the output power (shaft power) of a drive motor, 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_{sc}	is the short-circuit losses, W
P_{mech}	is the mechanical power, 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 (see 4.2)
R	is a winding resistance, Ω
R_{eh}	is the actual value of the auxiliary resistor for the Eh-star test (see 6.2.5), Ω
R'_{eh}	is the typical value of the auxiliary resistor, Ω
R_f	is the field winding resistance, Ω

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_{ll}	is the line-to-line-resistance (average of all phases), Ω
R_{ph}	is the phase-resistance (average of all phases), Ω
s	is the slip, in per unit value of synchronous speed
T	is the machine torque, $N \cdot m$
T_d	is the reading of the torque measuring device, $N \cdot m$
U	is the terminal voltage (average of all phases), V
U_0	is the terminal voltage at no-load (average of all phases), 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
α	is a temperature coefficient
η	is the efficiency
θ_0	is the initial winding temperature, $^{\circ}C$
θ_a	is the ambient temperature, $^{\circ}C$
θ_c	primary coolant inlet temperature, $^{\circ}C$
θ_w	is the winding temperature, $^{\circ}C$
τ	is a time constant, s

4.2 Additional subscripts

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

Machine components:

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

Machine categories:

B	booster
E	exciter
G	generator
M	motor

Operating conditions:

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

NOTE Further additional subscripts are introduced in relevant subclauses.

5 Basic requirements

5.1 Direct and indirect efficiency determination

Tests can be grouped into the three following categories:

- input-output power measurement on a single machine. This involves the direct measurement of electrical or mechanical power into, and mechanical or electrical power out of a machine;
- electrical 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;
- determination of the actual loss in a machine under a particular condition. This is usually not the total loss but comprises certain loss components.

The methods for determining the efficiency of machines are based on a number of assumptions. Therefore, it is not recommended that a comparison be made between the values of efficiency obtained by different methods, because the figures may not necessarily agree.

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 shall be expressed as a numerical value, such a requirement needs sufficient testing to determine representative and comparative values.

5.3 Preferred methods and methods for customer-specific acceptance tests, field-tests or routine-tests

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).

In the following, the test methods suitable for asynchronous and synchronous machines are separated into preferred methods and methods for customer-specific acceptance tests, field-tests or routine tests.

5.4 Power supply

5.4.1 Voltage

The supply voltage shall be in accordance with 7.2 (and 8.3.1 for thermal tests) of IEC 60034-1:2022.

5.4.2 Frequency

During tests, the average supply frequency shall be within $\pm 0,1$ % of the frequency required for the test being conducted.

5.5 Instrumentation

5.5.1 General

Environmental conditions shall be within the recommended range given by the instrument manufacturer. If appropriate, temperature corrections according to the instrument manufacturer's specification shall be made.

Digital instruments shall be used whenever possible.

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

The full scale of the instrument, particularly the current sensors, shall be adapted to the power of the machine under test.

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

When testing electric machines under load, slow fluctuations in the output power and other measured quantities may be unavoidable. Therefore, for each load point many readings (typically many hundred readings) shall be taken automatically by a suitable digital meter over a period of several fluctuation cycles, at least 5 s but not more than 60 s and this average shall be used for the determination of efficiency.

5.5.2 Measuring instruments for electrical quantities

The measuring instruments shall have the equivalent of an accuracy class of 0,2 in case of a direct test and 0,5 in case of an indirect test in accordance with IEC 60051. The measuring equipment shall reach a maximum overall uncertainty of 0,2 % of reading at power factor 1,0 and shall include all errors of instrument transformers or transducers, if used.

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

In the case of AC machines, unless otherwise stated in this standard, the arithmetic average of the line currents and voltages shall be used.

5.5.3 Torque measurement

The torque measuring device shall have a minimum class of 0,2. The minimum torque measured shall be at least 10 % of the torque meter's nominal torque. This applies also to part load measurements, because of increased instrument uncertainty at small readings. If a better class instrument is used, the allowed torque range can be extended accordingly.

NOTE For example class 0,1 means 5 % of the torque meter's nominal torque.

Allowed torque measuring device are an inline torque meter or a reaction torque sensor between the machine and its base. In the latter case the machine is directly coupled to the load. See Figure 2.

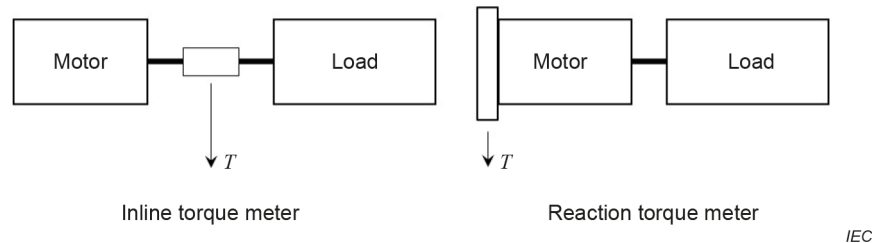


Figure 1 – Torque measuring devices

It shall be noted that the temperature of the torque sensor (i.e., due to proximity to the rotor) may be higher than the ambient temperature and is acknowledged to have a significant contribution to overall uncertainty. In that case the contribution of temperature to the uncertainty shall be limited to 0,15 % of full scale. If that is not practical, an appropriate temperature correction shall be applied.

Parasitic loads should be minimized by shaft alignment and the use of flexible couplings.

5.5.4 Speed and frequency measurement

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

NOTE For asynchronous machines, the measurement of slip by a suitable method may replace speed measurement (see Annex C).

5.5.5 Temperature measurement

The instrumentation used to measure temperatures shall have an accuracy of ± 1 K.

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 DC machines, R is the total resistance of all windings carrying armature current (armature, commutation, compensating winding, compound winding).

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

For polyphase AC machines, $R = R_{ll}$ is the line-to-line average resistance of the stator or armature winding according to 3.14.3. In the case of wound rotor induction machines, $R_{r,ll}$ is the rotor line-to-line average resistance.

The measured resistance at the end of the thermal test shall be determined as soon as possible but not after more than twice the interval as specified in Table 6 of IEC60034-1:2022. Additional readings shall be taken at intervals of approximately 1 min until these readings have begun a distinct decline from their maximum value. A curve of these readings shall be plotted as a function of time and extrapolated to zero. The value of temperature thus obtained shall be considered as the temperature at shutdown.

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

5.7.2 Winding temperature

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

- temperature determined from the rated load test resistance R_N by the extrapolation procedure as described in 5.7.1;
- temperature measured directly by either ETD or thermocouple; if the temperature is measured by more than one ETD or thermocouple, the average of all readings shall be taken;
- temperature determined according to a) on a duplicate machine of the same construction and electrical design;
- if load capability is not available, determine operating temperature according to IEC 60034-29;
- if the rated load test resistance R_N cannot be measured directly, the winding temperature shall be assumed to be equal to the reference temperature of the rated thermal class as given in Table 1.

Table 1 – 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.

Motors that are subject to check testing for regulatory purposes are not to be dismantled. In that case, measurement of winding temperature shall be by the change of resistance method;

5.7.3 Correction to reference coolant temperature

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

$$k_{\theta} = \frac{235 + \theta_w + 25 - \theta_c}{235 + \theta_w} \quad (1)$$

where

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

θ_c is the primary 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 aluminium conductors.

For machines with water as the primary or secondary coolant, the water reference temperature shall be 25 °C according to Table 5 of IEC 60034-1:2022. Alternative values may be specified by agreement.

5.8 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.

For handling of sealing systems for efficiency classification related measurements see IEC 60034-30-1.

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

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, then the specified thermal conditions shall be re-established prior to obtaining the test data.

For machines with adjustable brushes, the brushes shall be placed in the position corresponding to the specified rating. For 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 DC machines.

For machines having brushes, during the rated load test, and prior to any measurement, a visual inspection shall be done to check if the brushes are fully bedded, and a proper skin is developed.

The bearing losses depend on the operating temperatures of the bearings, the type of lubricant and lubricant temperature.

If the losses in a separate lubricating system of bearings are required these should be listed separately.

In the case of motors which are furnished with thrust bearings, only that portion of the thrust bearing loss produced by the motor itself shall be included in the total losses.

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.

5.9 Excitation circuit measurements

Determination of voltage U_e and current I_e (see 3.13.3.2) depends on the configurations of the excitation system (see 3.13.3.3). 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 3.13.3.3 a), c), d) and e)), voltage U_e and current I_e are measured:
 - at the excitation winding terminals of DC machines;
 - at the field winding slip-rings of synchronous machines;
- b) for machines excited by brushless exciters (see 3.13.3.3 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 of brushes) is in practice almost negligible.

Voltages and currents shall be measured at stabilized temperatures.

The excitation circuit losses P_e are determined according to 7.1.3.2.1.5 (synchronous machines) or 8.3.2.1.5 (DC machines).

5.10 Ambient temperature during testing

The ambient temperature should be in the range of 15 °C to 40 °C.

6 Test methods for the determination of the efficiency of induction machines

6.1 Preferred testing methods

6.1.1 General

This document defines three different preferred methods with low uncertainty within the given range of application, see Table 2. The specific method to be used depends on the type or rating of the machine under test:

Method 2-1-1A: Direct measurement of input and output power by using a torque measuring device. To be applied for all single phase machines.

Method 2-1-1B: Summation of separate losses. Additional load loss determined by the method of residual loss. To be applied for all three phase machines with rated output power up to 2 MW. See also Annex D.

Method 2-1-1C: Summation of separate losses. Additional load loss determined by the method of assigned value. To be applied for all three phase machines with rated output power greater than 2 MW.

Table 2 – Induction machines: preferred testing methods

Reference	Method	Description	Subclause	Application	Required facility
2-1-1A	Direct measurement: Input-output	Torque measurement	6.1.2	All single phase machines	Torque measuring device for full-load
2-1-1B	Summation of losses: Residual losses	P_{LL} determined from residual loss	6.1.3	Three phase machines with rated output power up to 2 MW	Torque measuring device for 1,25 × full-load, or load machine for 1,25 × full-load with torque measuring device
2-1-1C	Summation of losses: Assigned value	P_{LL} from assigned value	6.1.4	Three phase machines with rated output power greater than 2 MW	

6.1.2 Method 2-1-1A – Direct measurement of input and output

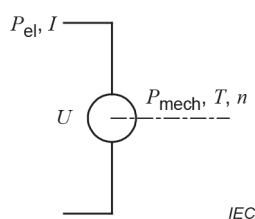
6.1.2.1 General

This is a test method 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 is measured in the same test.

Input and output power are:

$$\text{in motor operation: } P_1 = P_{\text{el}}; P_2 = P_{\text{mech}} \text{ (see Figure 2);} \quad (2)$$

$$\text{in generator operation: } P_1 = P_{\text{mech}}; P_2 = P_{\text{el}} \quad (3)$$

**Figure 2 – Sketch for torque measurement test**

For an overview, Figure 3 provides a flowchart for efficiency determination by this test method.

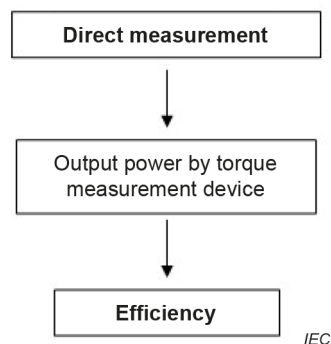


Figure 3 – Efficiency determination according to method 2-1-1A

6.1.2.2 Test procedure

Couple the machine under test to a load machine with torque measuring device. Operate the machine under test at the required load until thermal equilibrium is achieved (rate of change 1 K or less per half hour).

Record U , I , P_{el} , n , T , θ_c .

Immediately after the test, the drift of the torque measuring device shall be checked. In case of a deviation above the allowed tolerance of the torque measuring device, adjust it and repeat the measurements.

6.1.2.3 Efficiency determination

The efficiency is:

$$\eta = \frac{P_2}{P_1} \quad (4)$$

Input power P_1 and output power P_2 are:

$$\text{in motor operation: } P_1 = P_{el}; P_2 = P_{mech}; \quad (5)$$

$$\text{in generator operation: } P_1 = P_{mech}; P_2 = P_{el} \quad (6)$$

where

$$P_{mech} = 2\pi \times T \times n \quad (7)$$

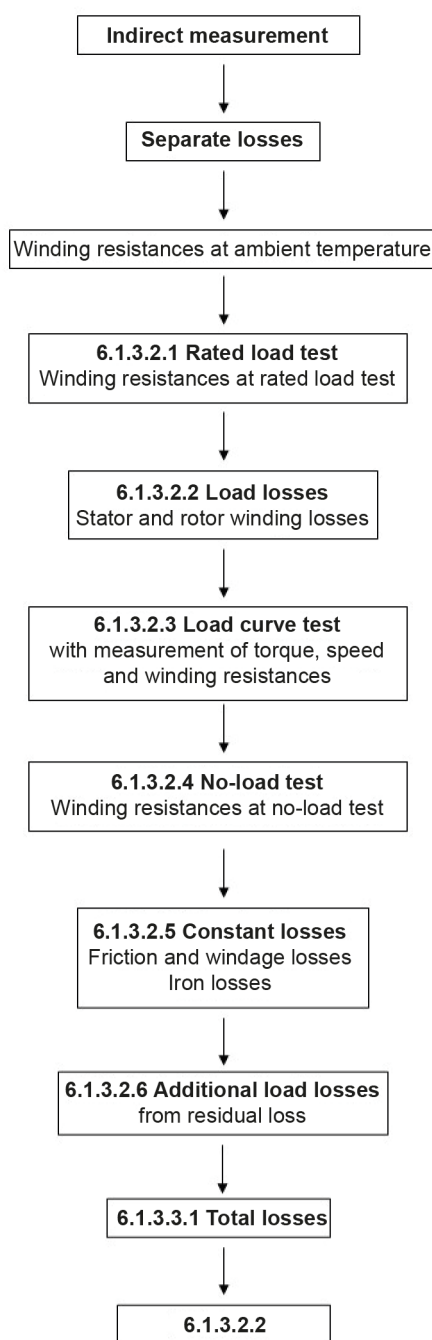
6.1.3 Method 2-1-1B – Summation of losses, additional load losses according to the method of residual loss

6.1.3.1 General

This is a test method in which the efficiency is determined by the summation of separate losses. The respective loss components are:

- iron loss;
- windage and friction losses;
- stator and rotor copper losses;
- additional load losses.

For an overview, Figure 4 provides a flowchart for efficiency determination by this test method.



IEC

Figure 4 – Efficiency determination according to method 2-1-1B

6.1.3.2 Test procedure

6.1.3.2.1 Rated load test

Before this load test, measure the temperature and the winding resistance of the motor with the motor at ambient temperature.

The machine shall be loaded by suitable means with rated output power and operated until thermal equilibrium is achieved (rate of change 1 K or less per half hour). Record the following quantities:

- $P_1, T, I, U, n, f, \theta_c, \theta$;
- $R_N = R$ (the test resistance for rated load according to 5.7.1);

– θ (the winding temperature at rated load according to 5.7.2).

Immediately after the load test, the drift of the torque transducer shall be checked. In case of a deviation above the allowed tolerance of the transducer, adjust it and repeat the measurements.

6.1.3.2.2 Load losses

6.1.3.2.2.1 Stator-winding losses and temperature correction

The uncorrected stator-winding losses at rated load are:

$$P_s = 1,5 \times I^2 \times R \quad (8)$$

where I and R are determined in 5.7.1.

Determine the stator-winding losses, using the stator winding resistance R_N from the rated load test, corrected to a reference coolant temperature of 25 °C:

$$P_{s,\theta} = P_s \times k_\theta \quad (9)$$

where k_θ is the correction according to 5.7.3 for the stator winding.

6.1.3.2.2.2 Rotor winding losses and temperature correction

For the uncorrected rotor winding losses use the formula:

$$P_r = (P_1 - P_s - P_{fe}) \times s \quad (10)$$

where

$$s = 1 - \frac{p \times n}{f} \quad (11)$$

P_1 , n and f are according to the rated load test;

P_s according to the load test as stated above;

P_{fe} is according to 6.1.3.2.5.

The corrected rotor winding losses are determined using the corrected value of the stator winding losses:

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

where

P_{fe} is according to 6.1.3.2.5 for a reference coolant temperature of 25 °C;

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

k_{θ} is the correction according to 5.7.3.

6.1.3.2.2.3 Temperature correction of input power (for a motor)

With the corrected stator and rotor winding losses, the corrected input power is:

$$P_{1,\theta} = P_1 - (P_s - P_{s,\theta} + P_r - P_{r,\theta}) \quad (12)$$

6.1.3.2.3 Load curve test

This test shall be carried out immediately after the rated load test with the motor at operating temperature.

If that is not possible, prior to the start of recording data for this test, the temperature rise of the windings shall be within 5 K of the initial temperature rise θ_N , obtained from a rated load temperature test.

Apply the load (shaft power) to the machine at the following six load points: approximately 125 %, 115 %, 100 %, 75 %, 50 % and 25 % of rated load. These tests shall be performed as quickly as possible to minimize temperature changes in the machine during testing.

NOTE 1 As an indication, the applied load may vary by ± 5 % from the figures given above. The impact on the further evaluation of the residual losses is limited.

Supply 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 varying linearly with load, using the reading before the test for the highest load and after the lowest reading for 25 % load.

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 measured resistance before load curve test multiplied with the ratio of the temperature of the winding at that load point to the temperature of the winding measured before the start of the test.

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

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

$$P_s = 1,5 \times I^2 \times R \quad (13)$$

where I and R are determined according to 6.1.3.2.2 for each load point.

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

$$P_r = (P_1 - P_s - P_{fe}) \times s \quad (14)$$

where

$$s = 1 - \frac{p \times n}{f} \quad (15)$$

P_1 , n and f are according to the load curve test;

P_s is according to the load curve test as stated above;

P_{fe} is according to 6.1.3.2.5.

6.1.3.2.4 No-load test

The no-load test shall be carried out on a hot machine immediately after the load curve test.

Alternatively, the test may also be carried out with stabilized no-load losses. 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.

Test at the following eight values of voltage, including rated voltage, so that:

- the values at approximately 110 %, 100 %, 95 % and 90 % of rated voltage are used for the determination of iron losses;
- the values at approximately 60 %, 50 %, 40 % and 30 % of rated voltage are used for the determination of windage and friction losses.

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 .

Determine the resistance R_0 immediately before and after the no-load test.

The interpolated winding resistance of each voltage point shall be calculated by interpolating the resistances before and after the test linearly with the electrical power P_0 .

For induction machines R_0 is $R_{ll,0}$. Where resistance measurement is impracticable due to very low resistances, calculated values are permissible.

NOTE Resistances may also be determined by measuring the stator winding temperature using a temperature-sensing device installed on the winding. Resistances for each voltage point may then be determined from measured resistance before no-load test multiplied with the ratio of the temperature of the winding at that load point to the temperature of the winding measured before the start of the test.

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

6.1.3.2.5 Constant losses

6.1.3.2.5.1 General

Subtracting the no-load winding losses 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.

$$P_c = P_0 - P_s = P_{fw} + P_{fe} \quad (16)$$

where

$$P_s = 1,5 \times I_0^2 \times R_{ll,0} \quad (17)$$

with $R_{ll,0}$ being the interpolated winding resistance at each voltage point.

6.1.3.2.5.2 Friction and windage losses

From the four or more consecutive no-load loss points between approximately 60 % of voltage and 30 % of voltage develop a curve of constant losses (P_c) against the voltage squared (U_0^2).

Extrapolate a straight line to zero voltage. Determine the intercept at zero voltage, which is considered the friction and windage losses P_{fw0} at approximately synchronous speed.

6.1.3.2.5.3 Iron losses

From the values of voltage between approximately 90 % and 110 % of rated voltage, develop a curve of $P_{fe} = P_c - P_{fw}$ against voltage U_0 .

To determine the iron losses at full load the inner voltage U_i that takes the resistive voltage drop in the primary winding into account shall be calculated:

$$U_i = \sqrt{\left(U - \frac{\sqrt{3}}{2} \cdot I \cdot R \cdot \cos \varphi \right)^2 + \left(\frac{\sqrt{3}}{2} \cdot I \cdot R \cdot \sin \varphi \right)^2} \quad \text{for a motor} \quad (18)$$

$$U_i = \sqrt{\left(U + \frac{\sqrt{3}}{2} \cdot I \cdot R \cdot \cos \varphi \right)^2 + \left(\frac{\sqrt{3}}{2} \cdot I \cdot R \cdot \sin \varphi \right)^2} \quad \text{for a generator} \quad (19)$$

Where

$$\cos \varphi = \frac{P_1}{\sqrt{3} \times U \times I}; \quad \sin \varphi = \sqrt{1 - \cos^2 \varphi} \quad (20)$$

U , P_1 , I and R are from the load test according to 6.1.3.2.1.

The iron losses at full load shall be interpolated from the iron losses over voltage U_0 curve at the voltage U_i .

NOTE The iron losses at full load may be calculated by using the ratio $(U_i/U_N)^2$ applied to the iron losses at no-load.

Because the stator leakage inductance is unknown, the voltage is only considering the resistive voltage drop. Due to the low power factor at no-load, the resistive voltage drop is negligible during the measurement itself and shall only be taken into consideration for the load values.

6.1.3.2.6 Additional load losses P_{LL}

6.1.3.2.6.1 Residual losses P_{Lr}

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

The iron losses at each load point shall be interpolated from the iron losses over voltage U_0 curve at the voltage U_i for the respective load point.

$$P_{Lr} = P_1 - P_2 - P_s - P_r - P_{fe} - P_{fw}; \quad (21)$$

$$P_2 = 2\pi \cdot T \cdot n \text{ for a motor and } P_1 = 2\pi \cdot T \cdot n \text{ for a generator.} \quad (22)$$

where

$$P_{fw} = P_{fw0} \cdot (1-s)^{2.5} \text{ with } s = 1 - \frac{p \times n}{f} \quad (23)$$

are the corrected friction and windage losses.

6.1.3.2.6.2 Smoothing of the residual loss data

The residual loss data shall be smoothed by using the linear regression analysis (see Figure 5) based on expressing the losses as a function of the square of the load torque according to the relationship:

$$P_{Lr} = A \times T^2 + B \quad (24)$$

A and B are constants determined from the six load points using the following formulas:

$$A \text{ is the slope according to } A = \frac{i \cdot \sum (P_{Lr} \cdot T^2) - \sum P_{Lr} \cdot \sum T^2}{i \cdot \sum (T^2)^2 - (\sum T^2)^2} \quad (25)$$

$$B \text{ is the intercept according to } B = \frac{\sum P_{Lr}}{i} - A \cdot \frac{\sum T^2}{i} \quad (26)$$

i is the number of load points summed.

The intercept B should be considerably smaller (< 50 %) than the additional load losses P_{LL} at rated torque. Otherwise the measurement may be erroneous and should be checked.

NOTE The intercept B may be positive or negative. Figure 5 shows an example for positive intercept B.

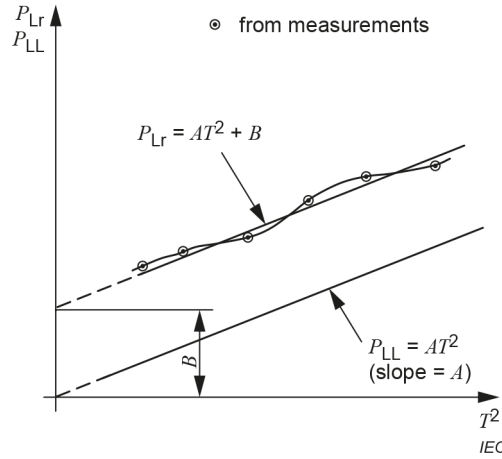


Figure 5 – Smoothing of the residual loss data

The correlation coefficient is calculated as

$$\gamma = \frac{i \cdot \sum (P_{Lr} \cdot T^2) - (\sum P_{Lr}) \cdot (\sum T^2)}{\sqrt{\left(i \cdot \sum (T^2)^2 - (\sum T^2)^2 \right) \cdot \left(i \cdot \sum P_{Lr}^2 - (\sum P_{Lr})^2 \right)}} \quad (27)$$

If the correlation coefficient γ is less than 0,95, delete the worst point and repeat the regression. If γ increases to $\geq 0,95$, 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 should be repeated. In case of sufficient test data, a correlation coefficient of 0,98 or better is likely.

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

$$P_{LL} = A \times T^2 \quad (28)$$

6.1.3.3 Efficiency determination

6.1.3.3.1 Total losses

The total losses shall be taken as the sum of the adjusted iron losses, the corrected friction and windage losses, the load losses and the additional load losses:

$$P_T = P_{fe} + P_{fw} + P_{s\theta} + P_{r\theta} + P_{LL}, \quad (29)$$

where

$$P_{fw} = P_{fw0} \cdot (1 - s_{\theta})^{2,5} \quad (30)$$

are the corrected friction and windage losses.

6.1.3.3.2 Efficiency

The efficiency is determined from

$$\eta = \frac{P_{1,\theta} - P_T}{P_{1,\theta}} = \frac{P_2}{P_2 + P_T} \quad (31)$$

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

where

$P_{1,\theta}$ is the temperature corrected input power from the rated load test;

P_2 is the output power from the rated load test.

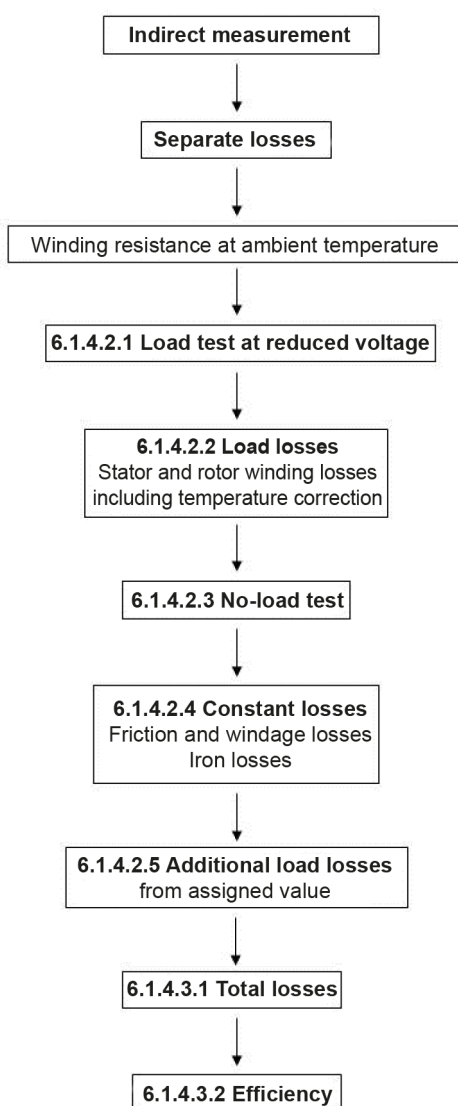
6.1.4 Method 2-1-1C – Summation of losses with additional load losses from assigned allowance

6.1.4.1 General

As method 2-1-1B, this test method determines efficiency by the summation of separate losses. For the reason that full load testing as required by method 2-1-1B is in general not practical for ratings above 2 MW, this method is based on a load test with reduced voltage and an assigned value for the additional load losses. Therefore the full load test and the load curve test are not required for method 2-1-1C.

Apart from this, method 2-1-1C is similar to method 2-1-1B.

For an overview, Figure 6 provides a flowchart for efficiency determination by this test method.



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Figure 6 – Efficiency determination according to method 2-1-1C

6.1.4.2 Test procedure

6.1.4.2.1 Load test at reduced voltage

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

Operate the machine using the maximum available load with a decrease in voltage to achieve rated speed. Operate to achieve thermal equilibrium.

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

At rated voltage and no-load, record: U_N , I_0 , $\cos(\varphi_0)$.

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

$$\underline{I} = I_{\text{red}} \frac{U_{\text{N}}}{U_{\text{red}}} + \Delta \underline{I}_0 \quad (32)$$

where

$$\Delta \underline{I}_0 = -j(|I_0| \sin \varphi_0 - |I_{0,\text{red}}| \frac{U_{\text{N}}}{U_{\text{red}}} \sin \varphi_{0,\text{red}}) \quad (33)$$

$$P_1 = P_{1,\text{red}} \times \left(\frac{U_{\text{N}}}{U_{\text{red}}} \right)^2 \quad (34)$$

NOTE Underlined current symbols indicate vectors (see Figure 7).

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 a load test at rated voltage.

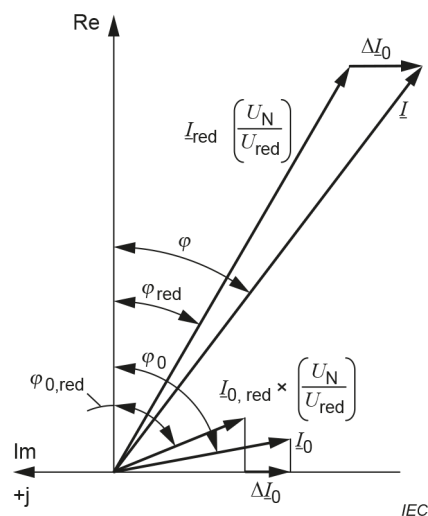


Figure 7 – Vector diagram for obtaining current vector from reduced voltage test

6.1.4.2.2 Load losses

The determination of load losses is similar to 6.1.3.2.2.

6.1.4.2.3 No-load test

The no-load test shall be carried out on a hot machine immediately after the load test.

The no-load test is similar to 6.1.3.2.4.

6.1.4.2.4 Constant losses

The determination of the constant losses is similar to 6.1.3.2.5.

6.1.4.2.5 Additional load losses P_{LL}

The value of additional load losses P_{LL} at rated load shall be determined as a percentage of input power P_1 using the curve in Figure 8.

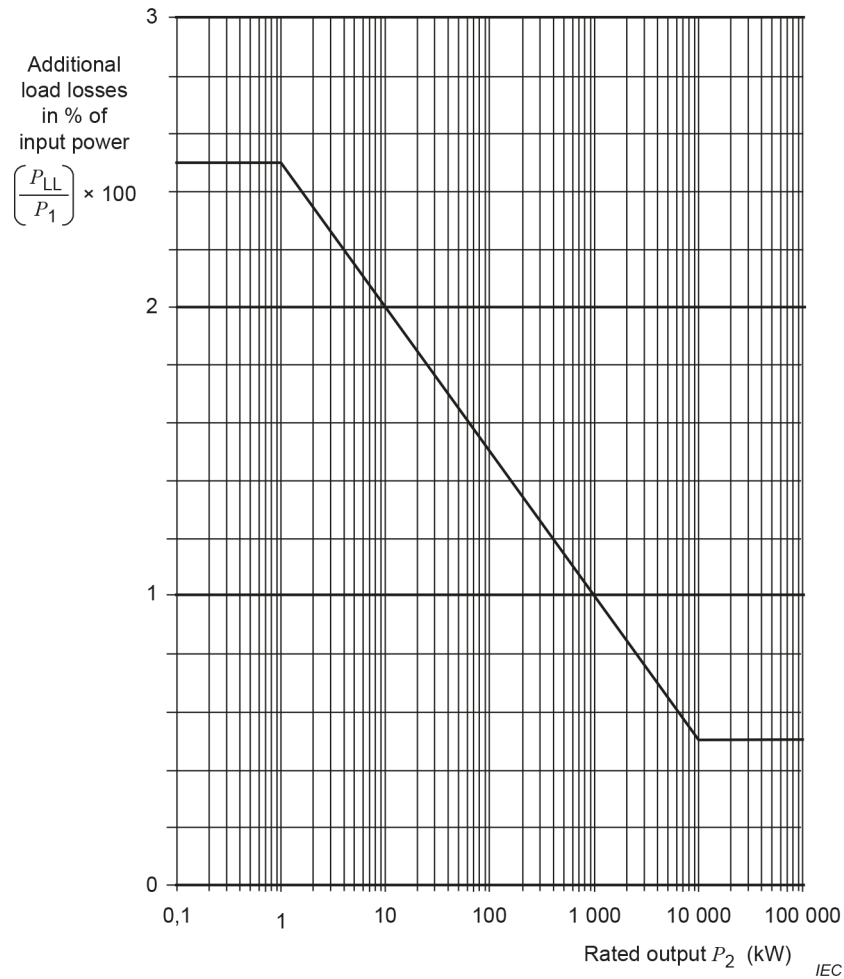


Figure 8 – Assigned allowance for additional load losses P_{LL}

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

$$\text{for } P_2 \leq 1 \text{ kW} \quad R_{LL} = P_1 \times 0,025$$

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

$$\text{for } P_2 \geq 10\,000 \text{ kW} \quad R_{LL} = P_1 \times 0,005$$

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:

$$P_{LL}(I) = P_{LL}(I_N) \times \frac{I^2 - I_0^2}{I_N^2 - I_{0N}^2}$$

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 6.1.3.

6.1.4.3 Efficiency determination

6.1.4.3.1 Total losses

The total losses shall be taken as the sum of constant losses, load losses and additional load losses:

$$P_T = P_C + P_S + P_r + P_{LL} \quad (35)$$

6.1.4.3.2 Efficiency

The efficiency is determined from

$$\eta = \frac{P_1 - P_T}{P_1} = \frac{P_2}{P_2 + P_T} \quad (36)$$

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

6.2 Testing methods for field or routine-testing

6.2.1 General

These test methods may be used for any test, i.e. field-tests, customer-specific acceptance tests or routine-tests.

In addition, preferred methods of Table 2 may also be used outside the power range identified in Table 2.

Methods defined by this document are given in Table 3.

Table 3 – Induction machines: other methods

Reference	Method	Description	Subclause	Required facility
2-1-1D	Dual-supply-back-to-back	Dual-supply, back-to-back test	6.2.2	Machine set for full-load; two identical units
2-1-1E	Single-supply-back-to-back	Single-supply, back-to-back test	6.2.3	Two identical units (wound rotor)
2-1-1F	Reverse rotation	P_{LL} from removed rotor and reverse rotation test	6.2.4	Auxiliary motor with rated power up to $5 \times$ total losses
2-1-1G	Eh-star	P_{LL} from Eh-star test	6.2.5	Winding shall be connected in star connection.
2-1-1H	Equivalent circuit	Currents, powers and slip from the equivalent circuit method, P_{LL} from assigned value	6.2.6	If test equipment for other tests is not available (no possibility of applying rated load, no duplicate machine)

6.2.2 Method 2-1-1D – Dual supply back-to-back-test

6.2.2.1 General

For an overview, Figure 9 provides a flowchart for efficiency determination by this test method.

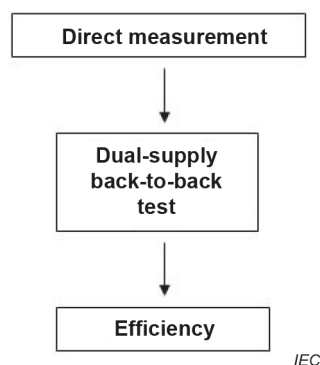


Figure 9 – Efficiency determination according to method 2-1-1D

6.2.2.2 Test procedure

Mechanically, couple two identical machines together (see Figure 10).

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

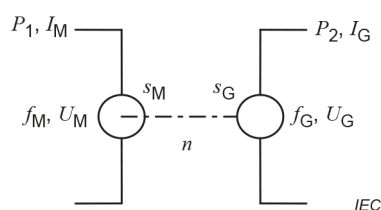


Figure 10 – Sketch for dual supply back-to-back test

Connect the driven machine (induction generator) terminals to either a machine set or a converter, 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 .

6.2.2.3 Efficiency determination

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

$$\eta = 1 - \frac{P_T}{\frac{P_1 + P_2}{2}} \quad (37)$$

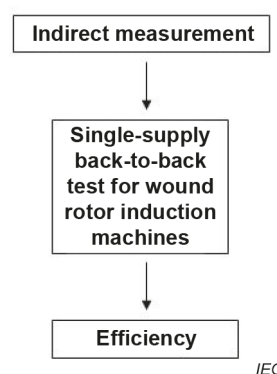
where

$$P_T = \frac{1}{2}(P_1 - P_2) \quad (38)$$

6.2.3 Method 2-1-1E – Single supply back-to-back-test

6.2.3.1 General

For an overview, Figure 11 provides a flowchart for efficiency determination by this test method.



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Figure 11 – Efficiency determination according to method 2-1-1E

6.2.3.2 Test procedure

This test is applicable to wound-rotor induction 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.

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 at the generator terminals;
- θ_c .

6.2.3.3 Efficiency determination

If 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

$$\eta = 1 - \frac{P_T}{P_M} \quad (39)$$

where

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

P_T is the total losses, defined as half the total absorbed, for wound-rotor induction machines

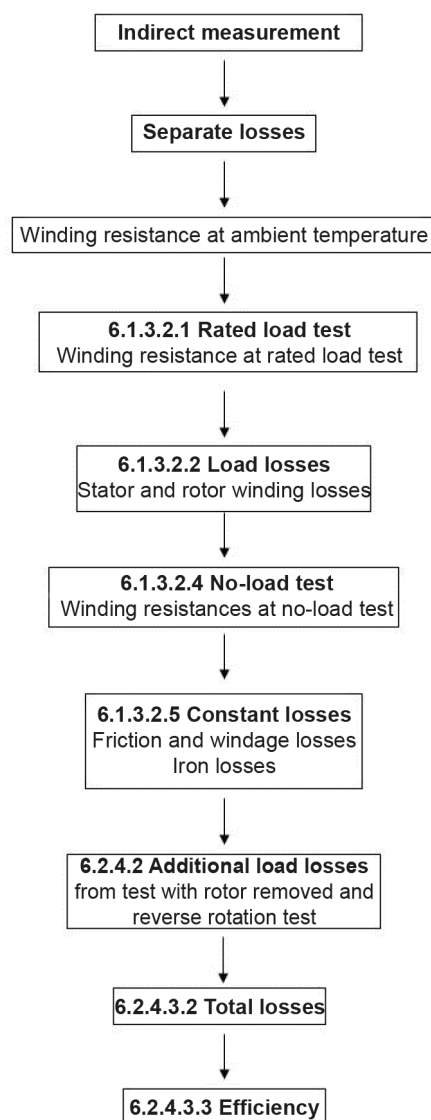
as follows: $P_T = \frac{1}{2}(P_1 + P_r)$

6.2.4 Method 2-1-1F – Summation of losses with additional load losses determined by test with rotor removed and reverse rotation test

6.2.4.1 General

As method 2-1-1B, this test method determines efficiency by the summation of separate losses. But in this case the additional load losses are determined by a combination of two individual tests: the test with rotor removed and the reverse rotation test. Apart from that, method 2-1-1F is similar to method 2-1-1B.

For an overview, Figure 12 provides a flowchart for efficiency determination by this test method.



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Figure 12 – Efficiency determination according to method 2-1-1F

6.2.4.2 Test procedure

Apart from the determination of the additional load losses, the same procedures as in 6.1.3.2 shall be applied, except that the torque does not need to be measured.

The required combination of tests for the determination of the additional load losses is as follows:

- with the rotor removed (for the fundamental frequency additional losses);
- 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 :

$$I_L = \sqrt{I^2 - I_0^2} \quad (40)$$

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.

NOTE Due to lack of cooling, the current is usually limited to 125 % or 115 % for 2-pole machines to reduce the risk of overheating.

6.2.4.2.1 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} , $\theta_{w,rm}$.

6.2.4.2.2 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. For wound-rotor machines, the rotor terminals shall be short-circuited.

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

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

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

6.2.4.3 Efficiency determination

6.2.4.3.1 Additional load losses

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

$$P_{1,rm} = A_{rm} \times I^{N1} + B_{L,rm}; \quad P_{1,rr} = A_{rr} \times I^{N2} + B_{L,rr}; \quad (P_{D,rr} - P_{0,rr}) = A_{D,rr} \times I^{N3} + B_{D,rr} \quad (41)$$

The smoothed powers will then be as follows:

$$P_{1,rm} = A_{rm} \times I^{N1}; \quad P_{1,rr} = A_{rr} \times I^{N2}; \quad (P_{D,rr} - P_{0,rr}) = A_{D,rr} \times I^{N3} \quad (42)$$

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

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

$$P_{LL,rm} = P_{1,rm} - (3 \times I^2 \times R_{s,rm}) \text{ is the fundamental frequency loss} \quad (43)$$

where

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

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

where

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

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

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

$$I_{NL} = \sqrt{I_N^2 - I_0^2} \quad (44)$$

where

I_N is the rated value of stator line current;

I_0 is the value of no-load stator current.

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

$$P_{NLL} = A_{Drr} \times I_{NL}^{N3} + 2A_{rm} \times I_{NL}^{N1} - A_{rr} \times I_{NL}^{N2} - 6I_{NL}^2 \times (R_{srm} - 0,5R_{srr}) \quad (45)$$

- b) Calculate the value of load current I_L at any operating point:

$$I_L = \sqrt{I^2 - I_0^2} \quad (46)$$

where

I is the stator line current at the operating point.

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

$$P_{LL} = P_{NLL} \times \left(\frac{I_L}{I_{NL}} \right)^2 \quad (47)$$

6.2.4.3.2 Total losses

The total losses shall be taken as the sum of constant losses, load losses and additional load losses:

$$P_T = P_c + P_s + P_r + P_{LL} \quad (48)$$

6.2.4.3.3 Efficiency

The efficiency is determined from

$$\eta = \frac{P_1 - P_T}{P_1} = \frac{P_2}{P_2 + P_T} \quad (49)$$

where

P_1 is the input power from a rated load test;

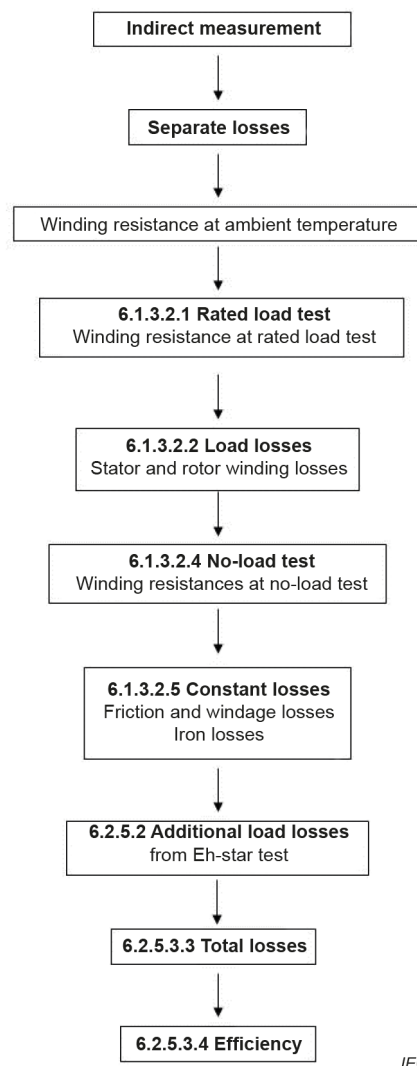
P_2 is the output power.

6.2.5 Method 2-1-1G – Summation of losses with additional load losses determined by Eh-star method

6.2.5.1 General

As method 2-1-1B, this test method determines efficiency by the summation of separate losses. But in this case the additional load losses are determined by the Eh-star test. Apart from that, method 2-1-1G is similar to method 2-1-1B.

For an overview, Figure 13 provides a flowchart for efficiency determination by this test method.



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Figure 13 – Efficiency determination according to method 2-1-1G**6.2.5.2 Test procedure**

Apart from the determination of the additional load losses, the same procedures as in 6.1.3.2 shall be applied.

The procedure for the determination of the additional load losses requires operating the uncoupled motor with unbalanced voltage supply. The test circuit is according to Figure 14.

Motors rated for and connected in delta-connection shall be reconnected to star-connection during this test. The star-point shall 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 14) having approximately the following typical value:

for motors rated for star-connection:
$$R'_{eh} = \frac{U_N}{\sqrt{3} \cdot I_N} \cdot 0,2 \quad (50)$$

for motors rated for delta-connection:
$$R'_{eh} = \frac{\sqrt{3} \cdot U_N}{I_N} \cdot 0,2 \quad (51)$$

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} .

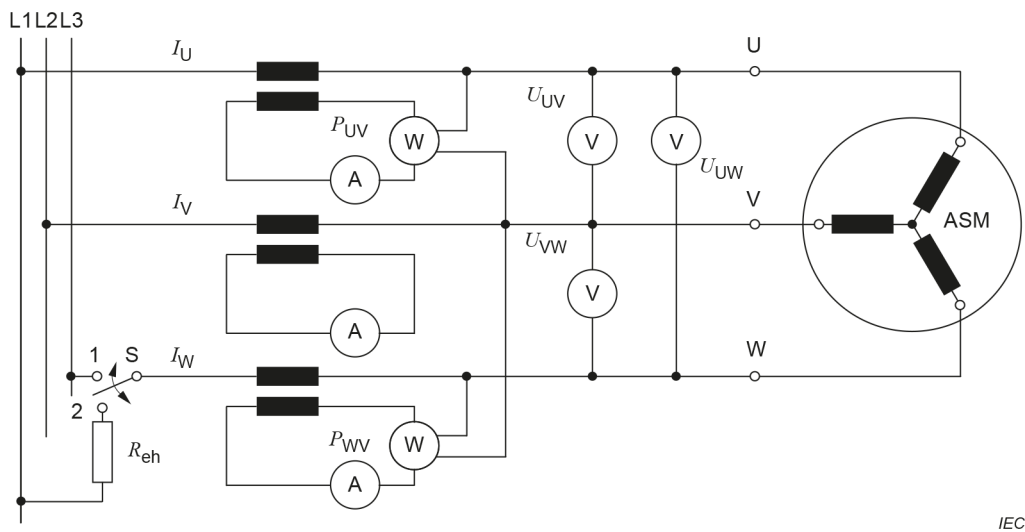


Figure 14 – Eh-star test circuit

Test current I_t is given by

for motors rated for star-connection:
$$I_t = \sqrt{I_N^2 - I_0^2} \quad (52)$$

for motors rated for delta-connection:
$$I_t = \frac{\sqrt{I_N^2 - I_0^2}}{\sqrt{3}} \quad (53)$$

Test voltage U_t is given by

for motors rated for star-connection:
$$U_t = U_N \quad (54)$$

for motors rated for delta-connection:
$$U_t = U_N \cdot \sqrt{3} \quad (55)$$

Prior to the test the no-load losses have to be stabilised according to 6.1.3.2.4.

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.

Large motors can only be started without the R_{eh} resistor (switch S to position 1, see Figure 14) at reduced voltage (25 % – 40 % U_N). After run-up connect R_{eh} by switching to position 2.

Small 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: $I_U, I_V, I_W, U_{UV}, U_{VW}, U_{WU}, P_{UV}, P_{WV}, n$.

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

NOTE 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.

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 14) 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.

6.2.5.3 Efficiency determination

6.2.5.3.1 Additional load losses

For each test point calculate the values using the formulas in Annex A.

6.2.5.3.2 Smoothing of the additional-load loss data

The additional-load loss data shall be smoothed by using the linear regression analysis (see Figure 5).

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 :

$$P_{Lr} = A \cdot \left(\frac{I_{l(2)}}{I_t} \right)^2 + B \quad (56)$$

A and B shall be computed similar to the procedure described in 6.1.3.2.6.

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

6.2.5.3.3 Total losses

The total losses shall be taken as the sum of constant losses, load losses and additional load losses:

$$P_T = P_c + P_s + P_r + P_{LL} \quad (57)$$

6.2.5.3.4 Efficiency

The efficiency is determined from

$$\eta = \frac{P_1 - P_T}{P_1} = \frac{P_2}{P_2 + P_T} \quad (58)$$

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;

P_2 is the output power.

6.2.6 Method 2-1-1H – Determination of efficiency by use of the equivalent circuit parameters

6.2.6.1 General

This method may be applied if 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 15). 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 $X'_{\sigma r}$.

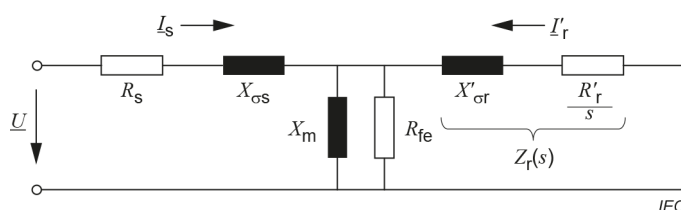


Figure 15 – Induction machine, T-model with equivalent iron loss resistor

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 reactance to 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 reactances.

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

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

For an overview, Figure 16 provides a flowchart for efficiency determination by this test method.

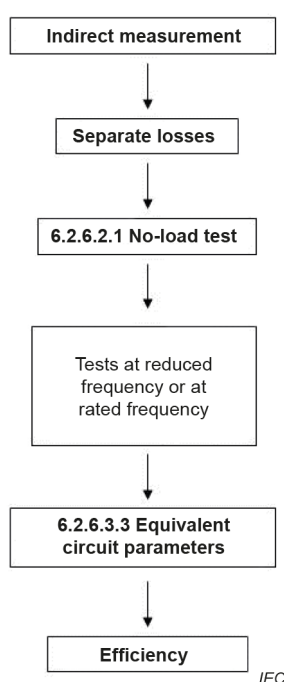


Figure 16 – Efficiency determination according to method 2-1-1H

6.2.6.2 Test procedure

6.2.6.2.1 No-load test

The no-load losses shall be stabilized at rated frequency and voltage.

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.

6.2.6.2.2 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.

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

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: $U, I, f, P_1, R_s, \theta_c, \theta_w$.

6.2.6.2.3 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.

6.2.6.3 Efficiency determination

6.2.6.3.1 Values from measurements

The method is based on the T-model circuit (see Figure 15).

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

The procedure described in this subclause is based on the test with reduced frequency. When using the test with rated frequency notice the following deviations:

- a) the reactances are calculated in the same manner as in the following;
- b) the rotor running resistance is determined:
 - using the test at rated frequency described in b) by reverse calculation using the equivalent circuit in Figure 15, 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 at rated frequency described in 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 formula:

$$R_r' = \frac{(X_m + X_{\sigma r}')}{2\pi f \tau_0} \quad (59)$$

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.