

Rotating electrical machines —

Part 2: Methods for determining losses and efficiency of rotating electrical machinery from tests (excluding machines for traction vehicles)

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National foreword

This British Standard is the English language version of EN 60034-2:1996, including amendments A1:1996 and A2:1996. It is identical with IEC 34-2:1972 plus IEC 34-2A:1974, including amendment 1 1995 and amendment 2 1996. It supersedes BS 4999-102:1987, which is withdrawn.

NOTE IEC 34-2A:1974 (first supplement to IEC 34-2:1972) is given in Annex B of EN 60034-2:1996.

Text introduced by amendments A1 and A2 is indicated by a sideline.

The UK participation in its preparation was entrusted to Technical Committee PEL/2, Rotating electrical machinery, which has the responsibility to:

- aid enquirers to understand the text;
- present to the responsible international/European committee any enquiries on the interpretation, or proposals for change, and keep the UK interests informed;
- monitor related international and European developments and promulgate them in the UK.

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Summary of pages

This document comprises a front cover, an inside front cover, pages i and ii, the EN title page, pages 2 to 47 and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

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English version

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Part 2: Methods for determining losses and efficiency of
rotating electrical machinery from tests
(excluding machines for traction vehicles)

(includes amendments A1:1996 and A2:1996)
(IEC 34-2:1972 + IEC 34-2A:1974 + A1:1995 + A2:1996)

Machines électriques tournantes
Partie 2: Méthodes pour la détermination des
pertes et du rendement des machines
électriques tournantes à partir d'essais
(à l'exclusion des machines pour véhicules de
traction)
(inclut les amendements A1:1996 et A2:1996)
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Drehende elektrische Maschinen
Teil 2: Verfahren zur Bestimmung der
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drehenden elektrischen Maschinen aus
Prüfungen (ausgenommen Maschinen
für Schienen- und Straßenfahrzeuge)
(enthält Änderungen A1:1996 und A2:1996)
(IEC 34-2:1972 + IEC 34-2A:1974 + A1:1995 +
A2:1996)

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CENELEC

European Committee for Electrotechnical Standardization
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Foreword

The text of the International Standard IEC 34-2:1972 + IEC 34-2A:1974, prepared by SC 2G, Test methods and procedures, of IEC TC 2, Rotating machinery, was approved by CENELEC as HD 53.2 S1 on 1974-12-11.

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For products which have complied with HD 53.2 S1:1974 (converted into EN 60034-2) before 1997-06-01, as shown by the manufacturer or by a certification body, this previous standard may continue to apply for production until 2002-06-01.

Foreword to amendment A2

The text of document 2/939/FDIS, prepared by IEC TC 2, Rotating machinery, was submitted to the formal vote and was approved by CENELEC as amendment A2 to EN 60034-2 on 1996-07-02.

The text of document 2G/73/FDIS, prepared by SC 2G, Test methods and procedures, of IEC TC 2, was submitted to the IEC-CENELEC parallel vote and was approved by CENELEC for inclusion into amendment A2 to EN 60034-2 on 1996-10-01.

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- latest date by which the national standards conflicting with the amendment have to be withdrawn (dow) 1997-06-01

For products which have complied with HD 53.2 S1:1974 (converted into EN 60034-2) before 1997-06-01, as shown by the manufacturer or by a certification body, this previous standard may continue to apply for production until 2002-06-01.

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Section 1. General

1 Scope

This Recommendation applies to d.c. machines and to a.c. synchronous and induction machines of all sizes within the scope of IEC Publication 34-1. The principles can, however, be applied to other types of machines such as rotary convertors, a.c. commutator motors and single-phase induction motors for which other methods of determining losses are generally use.

2 Object

This Recommendation is intended to establish methods of determining efficiencies from tests, and also to specify methods of obtaining particular losses when these are required for other purposes.

3 General

Tests shall be conducted on a completely sound machine with all covers fitted in the manner required for normal service, with any devices for automatic voltage regulation not a composite part of the machine itself being made inoperative, unless otherwise agreed.

Unless otherwise agreed, measuring instruments and their accessories, such as measuring transformers, shunts and bridges used during the test shall have an accuracy of 0,5 or better (IEC 51), excluding three-phase wattmeters and wattmeters for low power factor, for which an accuracy class shall be 1,0 or better.

Instruments shall be selected to give readings over the effective range such that a fraction of a division is a small percentage of the actual reading and can be easily estimated.

On machines with adjustable brushes, the brushes shall be placed in the position corresponding to the specified rating. For measurements on no-load, the brushes may be placed on the neutral axis.

Speed of rotation may be measured by a stroboscopic method, digital counter or tachometer. When measuring slip, the synchronous speed should be determined from the supply frequency during the test.

When the over-all efficiency or the absorbed power is measured for a group of machines comprising two electrical machines, or a machine and a transformer, or a generator and its driving machine, or a motor and its driven machine, there is no need to indicate the individual efficiencies. If, however, these are given separately, they should be regarded as approximate.

3.1 List of symbols

A list of symbols used in the draft, with the general meanings attributed to each one, is given below:

C	=	retardation constant
I	=	current
I_1	=	load current at rated voltage
I_{1r}	=	main primary current at reduced voltage
I_o	=	no-load current at rated voltage
I_{or}	=	no-load current at reduced voltage
J	=	moment of inertia
n	=	speed of rotation in revolutions per minute
n_N	=	rated speed
N	=	number of full revolutions of the shaft
P	=	losses which can be directly measured
P_1	=	power absorbed at rated voltage
P_{1r}	=	power absorbed by main primary winding at reduced voltage
P_{Fe}	=	iron losses defined in accordance with 6.2 a), 8.1 a) and 10.1 a)
P_f	=	friction and windage losses ("mechanical losses") defined in accordance with 6.2 b), 6.2 c), 8.1 b), 8.1 c), 10.1 b) and 10.1 c)
P_k	=	short-circuit losses representing the sum of the I^2R losses in operating windings on load in accordance with 10.2 and additional load losses in accordance with 10.4
P_t	=	total of the losses during the retardation test
S	=	angular displacement of the machine shaft
s	=	slip
U	=	excitation voltage across terminals of main rheostat
U_e	=	total excitation voltage
U_n	=	rated voltage
U_r	=	reduced voltage for load test
δ	=	per unit deviation of rotational speed from rated speed
φ	=	load phase angle at rated voltage
φ_r	=	load phase angle at reduced voltage
φ_o	=	no-load phase angle at rated voltage
φ_{or}	=	no-load phase angle at reduced voltage

- P_i = losses inside reference surface
 P_e = losses outside reference surface
 P_1 = losses which are dissipated by the cooling circuits in the form of heat and which can be measured calorimetrically
 P_2 = losses not transmitted to the cooling medium but which are dissipated through the reference surface by conduction, convection, radiation, leakage, etc.
 c_p = specific heat capacity of the cooling medium
 Q = volume rate of flow of the cooling medium
 ρ = density of the cooling medium
 Δt = rise in temperature of the cooling medium or temperature difference between the machine reference surface and the external ambient temperature
 v = exit velocity of cooling medium
 α = discharge coefficient
 e = error in measurement of losses, P_1 and P_2
 h = coefficient of heat transfer
 Δp = difference between the static pressure in the intake nozzle and ambient pressure
 A = cross-sectional area of the intake nozzle
 t = temperature
 t_1 = inlet temperature of the cooling medium
 t_2 = outlet temperature of the cooling medium
 b = barometric pressure

4 Definitions

For definitions of general terms used in this Recommendation, reference should be made to the International Electrotechnical Vocabulary [IEC Publication 50].

For the purpose of this Recommendation, the following definitions apply:

4.1 efficiency

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

4.2 total loss

the difference between the input and the output

4.3

braking test

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

4.4

calibrated driving machine test

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

4.5

mechanical back-to-back test

a 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 (see Figure 1, page 22)

4.6

electrical back-to-back test

a test in which two identical machines are mechanically coupled together, and they are both connected electrically to a power system. The total losses of both machines are taken as the power input drawn from the system (see Figure 2, page 22)

4.7

retardation test

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

4.8

calorimetric test

a test 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

4.9

no-load test

a test in which the machine is run as a motor providing no useful mechanical output from the shaft

4.10

open-circuit test

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

4.11**sustained short-circuit test**

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

4.12**zero power factor test**

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

5 Reference temperature

Unless otherwise specified, all I^2R losses shall be corrected to the temperatures given below:

Thermal class of the insulation system	Reference temperature °C
A, E	75
B	95
F	115
H	130

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.

Section 2. D.C. Machines**6 Losses to be included**

The total losses may be taken as the sum of the following component losses:

6.1 Excitation circuit losses

- I^2R losses in shunt or separately excited windings and in the excitation rheostats.
- Exciter losses.

All the losses in an exciter mechanically driven from the main shaft, which forms part of the complete unit and is used solely for exciting the machine, together with losses in the rheostat in the excitation circuit of such an exciter, but with the exception of friction and windage losses.

In the case of a separate excitation supply such as battery, rectifier or motor generator set, no allowance is made for the losses in the excitation source or in the connections between the source and the brushes.

NOTE When the losses in a separate excitation system are required, these should be listed separately and can be taken as the difference between the excitation power divided by the efficiency of the excitation system and the excitation power.

6.2 Constant losses

- Losses in active iron, and additional no-load losses in other metal parts.
- Losses due to friction (bearings and brushes) not including any losses in a separate lubricating system. Losses in common bearings shall be stated separately, whether or not such bearings are supplied with the machine.

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

- The total windage loss in the machine including power absorbed in integral fans and in auxiliary machines, if any, forming an integral part of the machine. The losses in auxiliary machines such as external fans, water and oil pumps not forming an integral part of the machine, but provided exclusively for the machine in question, shall be included only by agreement.

NOTE When the losses in a separate ventilating system are required, they should be listed separately as they are not part of the machine losses.

6.3 Load losses

- I^2R losses in armature, and windings carrying armature current (e.g. commutating, compensating, excitation and series connected windings).
- Electrical losses in brushes.

6.4 Additional load losses

- Losses introduced by load in active iron, and other metal parts other than the conductors.
- Eddy current losses in armature conductors caused by current dependent flux pulsation and commutation.
- Losses in the brushes caused by commutation.

NOTE These losses are sometimes called additional losses, but they do not include the additional no-load losses in Sub-clause 6.2 a).

7 Determination of efficiency

7.1 Summation of losses

The efficiency can be calculated from the total losses which are assumed to be the summation of the losses obtained in the following manner:

7.1.1 Excitation losses

These are:

7.1.1.1 Excitation winding I^2R losses

These losses are calculated from the formula I^2R , where R is the resistance of the shunt excitation winding (or separately excited winding), corrected to the reference temperature, and I is the excitation current. Except for case c) below, the excitation current shall be that corresponding to rated speed under rated load conditions. For case c) below, the excitation current shall be that corresponding to rated speed at no-load.

If the excitation current cannot be measured during a test on load, it should be taken as:

- For shunt connected or separately excited generators with or without commutation poles; 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 Sub-clause 7.1.3.2) at rated load current.
- For compensated shunt or separately excited generators: the excitation current corresponding to no-load at a voltage equal to the rated voltage plus the ohmic drop in the armature circuit (armature, brushes, commutating windings and compensating windings, see also Sub-clause 7.1.3.2) at rated load current.
- For level-compounded generators: the excitation current for the rated no-load voltage.
- For over-compounded and under-compounded generators, and special types of generator not covered by items a) to c): as agreed between manufacturer and purchaser.
- For shunt wound motors: equal to no-load excitation current corresponding to the rated voltage.

7.1.1.2 Main rheostat losses

These losses are calculated from the formula I^2R , where R is the resistance of the part of the rheostat in circuit for the rating considered, and I is the value of the excitation current defined as in Sub-clause 7.1.1.1 above. They are also equal to the product, IU , of the excitation current multiplied by U , the excitation voltage which must be absorbed in the rheostat.

The sum of the losses, Sub-clauses 7.1.1.1 and 7.1.1.2, is also equal to the product IU_e of the excitation current I and the total excitation voltage U_e .

NOTE Where a resistance is permanently connected in series in the excitation circuit it should be dealt with in the same way as the main rheostat.

7.1.1.3 Exciter losses

NOTE This applies only to the case where the exciter is mechanically driven from the main shaft and is used solely for exciting the main machine.

These losses include the difference between the power absorbed at the shaft by the exciter and the useful power which it provides at its terminals,¹⁾ as well as the excitation losses in the exciter if this is excited from a separate source.

If the exciter can be uncoupled from the main machine and tested separately, the power which it absorbs may be measured by using the calibrated-machine method.

If the exciter cannot be uncoupled from the main machine, the power which it absorbs may be measured either by the method of working the main machine as a motor on no-load, or by the calibrated machine method (Clause 13), or by the retardation method (Clause 15), applied to the whole unit. In these three methods, the power absorbed by the exciter is obtained as the difference between the total losses of the unit measured under identical conditions, first with the exciter on-load and secondly with the exciter non-excited, the excitation being supplied by an independent source.

If none of these methods is applicable, the power absorbed by the exciter is obtained by adding to the power, measured at the terminals, the different separate losses determined as under Clause 6. However, mechanical friction and windage losses which are measured at the same time as those of the main machine need not be taken into account.

7.1.2 Constant losses

7.1.2.1 No-load test at rated voltage

The constant losses shall be determined by running the machine under no-load conditions as a motor with rated voltage applied and with rated speed achieved by adjustment of the excitation, which shall preferably be derived from a separate source.

The total electric power absorbed, less the I^2R losses in the armature and in the excitation winding or, if necessary, less the power absorbed by the exciter, gives the sum of the constant losses.

¹⁾ The useful power at the terminals of the exciter is equal to the sum of the losses, Sub-clauses 7.1.1.1 and 7.1.1.2, of the main machine.

7.1.2.2 Open circuit test

The constant losses can be determined separately by driving the machine at its rated speed by means of a calibrated machine. The machine on test is excited (preferably from an independent source), so as to work as a generator on no-load at a voltage equal to its rated voltage, the power which it absorbs at its shaft, and which can be obtained from the electric power absorbed by the calibrated machine, giving the sum of the constant losses. By removing the excitation, the sum of the friction and windage losses is obtained in the same way. The core losses may be determined separately by subtracting the losses during this test from those measured during the previous no-load test. By lifting the brushes the brush friction loss may be determined separately by subtracting the losses during this test from those measured during the previous, unexcited test.

7.1.2.3 Retardation test

In machines with large inertia, the total constant losses, as well as the separate constant losses, can be determined by the retardation method.

7.1.3 Load losses

These are:

7.1.3.1 Armature circuit I^2R losses

These losses are calculated from the current and the measured resistance, corrected to the reference temperature, except that where resistance measurement is impracticable due to very low resistances, calculation is permissible.

NOTE Under this heading are included compensating windings, commutating pole windings and diverters. In the case of diverters in parallel with a series winding, the I^2R losses should be determined using the total current and the resulting resistance.

7.1.3.2 Electrical losses in brushes

The sum of these losses shall be taken as the product of the armature current and a fixed voltage drop.

The voltage drop allowed for all brushes of each polarity shall be 1.0 V for carbon or graphite brushes and 0.3 V for metal-carbon brushes, i.e. a total drop of 2.0 V for carbon or graphite brushes, and 0.6 V for metal-carbon brushes.

7.1.4 Additional load losses

Unless otherwise specified, it is assumed that these losses vary as the square of the current, and that their total value at maximum rated current is, for:

Uncompensated machines

1 % of the rated input for motors;

1 % of the rated output for generators.

Compensated machines

0.5 % of the rated input for motors;

0.5 % of the rated output for generators.

For constant speed machines, the rated output or input as appropriate is taken as the output or input which would be obtained at maximum rated current and maximum rated voltage.

For variable speed motors where the speed change is obtained by applied voltage, the rated input is defined at each speed as being the input when the maximum rated current at any speed 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 is defined as being the input 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 is defined as being the output 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. The allowances for additional losses at other speeds shall be calculated using the appropriate multiplying factors given in Table I, 36.

Multiplying factors for different speed ratios

Speed ratio	Multiplying 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 I 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 I the appropriate multiplying factors can be ascertained by interpolation.

NOTE The additional load loss may be obtained from an input-output test or from a back-to-back test by subtracting from the total measured losses all other known losses.

7.1.4.1 Change in core loss due to load

In general, this variation is usually negligible. By special agreement, for very low voltage machines, the sum, Sub-clause 6.2 a) and 6.4 a), may be measured as described for the constant losses in active iron, Sub-clause 6.2 a) by one or other of the two methods, by operating as a motor on no-load or as a generator on no-load, but instead of making the test at the rated voltage, the test is made at the rated voltage increased or decreased by the voltage drop in the armature circuit for the current considered, depending on whether the machine is a generator or a motor.

7.1.4.2 Additional load losses in d.c. motors supplied by static power converters

Whenever the current ripple factor (see **2.29**, IEC 34-1:1994) of the armature current exceeds 0,1, the additional losses caused by the a.c. component of the armature current shall be considered in addition to the losses specified in **7.1.4**.

They shall be calculated as the eddy current losses caused by the fundamental component of the above-mentioned a.c. component.

The method of calculation used shall be the subject of agreement between manufacturer and purchaser.

7.2 Total loss measurement**7.2.1 Electrical back-to-back tests (see clause 16)**

When identical machines are run at essentially the same rated conditions, the losses supplied from the electrical system are assumed to be equally distributed and the efficiency is calculated as **7.3.3**.

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.

7.3 Direct measurement of efficiency**7.3.1 Braking test**

When the machine is run at rated conditions of speed, voltage and current, the efficiency is then 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.

7.3.2 Calibrated machine test (see clause 13)

When the machine is run 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.

7.3.3 Mechanical back-to-back test

When identical machines are run at essentially the same rated conditions, the losses are assumed to be equally distributed, and the efficiency is calculated from half the total losses and the electrical input (in the case of a motor) or electrical output (in the case of a generator).

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.

Section 3. Polyphase induction machines**8 Losses to be included**

The total losses may be taken as the sum of the following component losses:

8.1 Constant losses

- a) Losses in active iron, and additional no-load losses in other metal parts.
- b) Losses due to friction (bearings and brushes, if not lifted during operation) not including any losses in a separate lubricating system. Losses in common bearings shall be stated separately whether or not such bearings are supplied with the machine.

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

- c) The total windage loss in the machine, including power absorbed in integral fans, and in auxiliary machines, if any, forming an integral part of the machine. The losses in auxiliary machines such as external fans, water and oil pumps not forming an integral part of the machine, but provided exclusively for the machine in question, shall be included only by agreement.

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

8.2 Load losses

- a) I^2R losses in primary windings.
- b) I^2R losses in secondary windings.
- c) Electrical losses in brushes (if any).

8.3 Additional load losses

- a) Losses introduced by load in active iron and other metal parts other than the conductors.
- b) Eddy current losses in primary or secondary winding conductors caused by current dependent flux pulsation.

NOTE 1 Losses, Sub-clause **8.3 a)** and **b)**, are sometimes called additional losses, but they do not include the additional no-load losses in Sub-clause **8.1 a)**.

NOTE 2 In the case of auxiliary machines such as phase advancers driven mechanically from the main shaft, the losses should be included in the same way as the exciter losses are included for synchronous machines. Losses in separately driven phase advancers or regulating equipment should be given separately for rated operating conditions of the main machine. These losses should be determined by the standard method for the types of apparatus involved.

9 Determination of efficiency

9.1 Summation of losses

The efficiency can be calculated from the total losses which are assumed to be the summation of the losses obtained in the following manner:

9.1.1 Constant losses

9.1.1.1 No-load test at rated voltage

The sum of the constant losses, Sub-clause 8.1 a), b) and c), is determined by running the machine as a motor on no-load. The machine is fed at its rated voltage and frequency. The power absorbed, decreased by the I^2R losses in the primary winding, gives the total of the constant losses. The I^2R losses in the secondary winding may be neglected.

9.1.1.2 Calibrated machine test (see Clause 13)

The constant losses may be determined separately by driving the machine, disconnected from the network, at its rated speed by means of a calibrated motor (see Sub-clause 9.2.2). With the brushes, if any, in place, the power absorbed at the shaft of the machine, which may be deduced from the electrical power absorbed by the calibrated motor, gives the sum of the losses in Sub-clause 8.1 b) and 8.1 c).

With the brushes, if any, lifted the sum of the bearing friction losses and the total windage losses is obtained in the same manner. The losses described in Sub-clause 8.1 a) may be obtained from the test described in Sub-clause 9.1.1.1 by subtraction.

9.1.1.3 No-load test at variable voltage

The losses described in Sub-clause 8.1 a) and the sum of the losses described in Sub-clause 8.1 b) and c) may alternatively be separated by running the machine as a motor at rated frequency but at different voltages. The power absorbed, less the I^2R losses in the primary winding, is plotted against the square of the voltage. This, at low values of saturation, will give a straight line which can be extrapolated to zero voltage to give the sum of the losses, Sub-clause 8.1 b) and c).

It should be borne in mind that at very low voltages, losses plotted on the diagram may be high because of the increased secondary winding losses with increased slip. When plotting the straight line, those values should not be taken into account.

If the motor is started with a short-circuited secondary winding and the brushes are lifted (which is possible if the supply generator is started at the same time as the motor) the bearing friction and total windage losses are obtained at zero voltage by extrapolation as above.

NOTE For wound rotor motors a synchronous no-load test can be carried out as for synchronous machines with d.c. excitation in two rotor phases (or three if desired).

9.1.2 Load losses

9.1.2.1 Load test

The losses described in Sub-clause 8.2 a) are calculated from the resistance of the primary windings measured using direct current and corrected to the reference temperature, and from the current corresponding to the load at which the losses are being calculated.

To determine the losses in Sub-clause 8.2 b) when an on-load test is made the secondary winding losses are taken to be equal to the product of the slip and the total power transmitted to the secondary winding, i.e. the power absorbed, decreased by the core losses in Sub-clause 8.1 a) and the I^2R losses in the primary winding in Sub-clause 8.2 a). This method gives directly the sum of the losses in Sub-clauses 8.2 b) and 8.2 c) for wound rotor machines, and the losses in Sub-clause 8.2 b) for cage machines. For this latter type of machine, this is the only applicable method as it is not possible to measure the resistance and current of the secondary winding directly. When use is made of this method, the slip may be measured by a stroboscopic method or by counting the beats of a permanent-magnet millivoltmeter connected between two rings (for motors with wound secondary windings) or the terminals of an auxiliary coil (for motors with short-circuited secondary windings) or between the ends of the shaft.

9.1.2.2 Calculated values

For wound rotor motors, the losses in Sub-clause 8.2 b) may be calculated from the resistance measured by direct current and corrected to the reference temperature, and from the secondary current calculated from a circle diagram or equivalent circuit, account being taken of the true transformation ratio of the machine. The type of circle diagram to be used should be agreed between manufacturer and purchaser.

To make an on-load test, the losses in Sub-clause 8.2 c) in the brushes cannot be measured directly and these losses shall be taken as the product of the current flowing in the brushes and a fixed voltage drop. The voltage drop in all brushes of the same phase shall be taken as 1.0 V for carbon or graphite brushes, and 0.3 V for metal-carbon brushes.

9.1.2.3 Load test at reduced voltage

This method is also applicable to cage rotor machines.

When the voltage is reduced, while keeping the rotational speed of the machine constant, the currents diminish approximately in proportion to the voltage, and the power approximately in proportion to the square of the voltage. When the voltage is down to half its rated value, the currents will then be reduced to about one half, and the power to about one quarter, of their values at the rated voltage.

When a load is applied to an induction motor at a reduced voltage U_r , the power absorbed P_{1r} , the main primary current I_{1r} and the slip s are measured, as well as the no-load current I_{0r} at the same reduced voltage U_r , and the no-load current I_0 at the rated voltage U_n .

The current vector I_t of the load at rated voltage is obtained by constructing a vector diagram (Figure 3, page 23) in the following manner:

To the current vector I_{1r} , multiplied by the ratio

$$\frac{\text{rated voltage}}{\text{reduced voltage}} = \frac{U_n}{U_r}$$

add the vector:

$$\Delta I_0 = I_0 \sin \varphi_0 - I_{\alpha r} \left(\frac{U_n}{U_r} \right) \sin \varphi_{\alpha r}$$

The resultant vector represents the current which would flow at the rated voltage U_n for the following absorbed power:

$$P_1 = P_{1r} \left(\frac{U_n}{U_r} \right)^2$$

By means of the values I_1 , P_1 , thus determined, and with the slip s measured at reduced voltage, it is then possible to calculate the on-load losses, as indicated in Sub-clause 9.1.2.1.

9.1.3 Additional load losses

Unless otherwise specified, it is assumed that the losses specified in Sub-clauses 8.3 a) and 8.3 b) vary as the square of the primary current and that their total value at full load is equal to 0.5 % of the rated input for motors and 0.5 % of the rated output for generators.

NOTE For some designs of small machines these losses might be higher than 0.5 % of the rated input. If, for a particular case, the value is of importance, the loss should be determined by the direct method of efficiency measurement.

9.2 Total loss measurement

9.2.1 Electrical back-to-back test (see clause 16)

When Identical machines are run at essentially the same rated conditions, the losses supplied from the electrical system are assumed to be equally distributed and the efficiency is calculated from half the total losses and the electrical input to one machine.

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 Where a gear box is required, as in the case of induction motors, it is necessary for the loss in this to be deducted from the electrical input before determining the losses in the electrical machine.

9.3 Direct measurement of efficiency

9.3.1 Braking test

When the machine is run 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.

9.3.2 Calibrated machine test (see clause 13)

When the machine is running in accordance with clause 13 at rated conditions of speed, voltage and current, the efficiency is then 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.

9.3.3 Mechanical back-to-back test

When identical machines are run at essentially the same rated conditions, the losses are assumed to be equally distributed, and the efficiency shall be calculated from half the total loss and the electrical input. The driven machine operates as an induction generator if a source of reactive power is provided, and a suitable load is connected to its terminals.

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.