IEC 60034-2-2

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INTERNATIONAL STANDARD

NORME INTERNATIONALE

Rotating electrical machines –
Part 2-2: Specific methods for determining separate losses of large machines from tests – Supplement to IEC 60034-2-1

Machines électriques tournantes –
Partie 2-2: Méthodes spécifiques pour déterminer les pertes séparées des machines de grande taille à partir d'essais – Complément à la CEI 60034-2-1

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IEC Central Office
3, rue de Varembé
CH-1211 Geneva 20
Switzerland
Email: inmail@iec.ch
Web: www.iec.ch

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Email: csc@iec.ch
Tél.: +41 22 919 02 11
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FOREWORD

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

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

FDIS	Report on voting
2/1585/FDIS	2/1595/RVD

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

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

NOTE A table of cross-references of all IEC TC 2 publications can be found in the IEC TC 2 dashboard on the IEC website.

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

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- withdrawn,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

ROTATING ELECTRICAL MACHINES –

Part 2-2: Specific methods for determining separate losses of large machines from tests – Supplement to IEC 60034-2-1

1 Scope

This part of IEC 60034 applies to large rotating electrical machines and establishes additional methods of determining separate losses and to define an efficiency supplementing IEC 60034-2-1. These methods apply when full-load testing is not practical and result in a greater uncertainty.

NOTE In situ testing according to the calorimetric method for full-load conditions is recognized.

The specific methods described are:

– Calibrated-machine method.

– Retardation method.

– Calorimetric method.

2 Normative references

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

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

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

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60034-1 and IEC 60034-2-1 apply, as well as the following.

3.1
calibrated machine
machine whose mechanical power input/output is determined, with low uncertainty, using measured electrical output/input values according to a defined test procedure

3.2
calibrated-machine method
method in which the mechanical input/output to/from an electrical machine under test is determined from the measurement of the electrical input/output of a calibrated machine mechanically coupled to the test machine

3.3
retardation method
method in which the separate losses in a machine under test are deduced from the measurements of the deceleration rate of its rotating components when only these losses are present

3.4
calorimetric method
method in which the losses in a machine are deduced from the measurements of the heat generated by them

3.5
thermal equilibrium
the state reached when the temperature rises of the several parts of the machine do not vary by more than a gradient of 2 K per hour

[IEV 411-51-08]

4 Symbols

In addition to the symbols in IEC 60034-2-1, the following apply.

4.1 Quantities

A is an area, m^2,

C is the retardation constant, kg m^2 min^2,

c_p is the specific heat capacity of the cooling medium, J/(kg K),

h is the coefficient of heat transfer, W/(m^2 K),

J is the moment of inertia, kg m^2,

n is the speed, min^{-1},

P_1E is the excitation power supplied by a separate source, W,

P_k is the constant loss, W,

P_el is the electrical power, excluding excitation, W,

P_e is the excitation power, W,

P_Fe is the iron loss, W,

P_fw is the friction and windage loss, W,

P_sc is the short-circuit loss, W,

P_mech is the mechanical power, W,

P_T is the total loss, W,

Q is the volume rate of flow of the cooling medium, m^3/s,

t is the time, s,

v is the exit velocity of cooling medium, m/s,

Δp is the difference between the static pressure in the intake nozzle and ambient pressure, N/m^2,

$\Delta\theta$ is the temperature rise of the cooling medium, or the temperature difference between the machine reference surface and the external ambient temperature, K,

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

ρ is the density of the cooling medium, kg/m^3,

θ is the temperature, °C.

4.2 Subscripts

irs for inside reference surface,

ers for outside reference surface,

E for exciter,

c for the cooling circuit,

N for rated values,

rs for the reference surface,

t for a test procedure,

1 for input or initial condition,

2 for output condition.

5 Basic requirements

5.1 Direct and indirect efficiency determination

Tests can be grouped in the following categories.

5.1.1 Direct

Input-output measurements on a single machine are considered to be direct. This involves the measurement of electrical or mechanical power into, and mechanical or electrical power out of a machine.

5.1.2 Indirect

Measurements of the separate losses in a machine under a particular condition are considered to be indirect. This is not usually the total loss but comprises certain loss components. The method may, however, be used to calculate the total loss or to calculate a loss component.

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

– direct measurement of total loss;

– summation of separate losses.

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

5.2 Uncertainty

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

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

– "low" applies to efficiency determinations based solely upon test results;

– "medium" applies to efficiency determinations based upon limited approximations;

– "high" applies to efficiency determinations based upon assumptions.

5.3 Preferred methods

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

Preferred methods for large machines are given in Table 1.

Table 1 – Preferred methods for large machines

Quantity to be determined	Test method	Clause	Uncertainty
Direct efficiency	Calibrated machine	7.1.4.1	medium
Total losses	Calorimetric [1]	7.3.3d)	low/medium
Friction and windage loss	Calibrated machine	7.1.4.2a)	medium
	Retardation	7.2.5.2	medium
	Calorimetric	7.3.3a)	low/medium
Active iron loss, and additional open-circuit losses in d.c. and synchronous machines	Calibrated machine	7.1.4.2b)	medium
	Retardation	7.2.5.3	medium
	Calorimetric	7.3.3b)	low/medium
Winding and additional-load losses	Calibrated machine	7.1.4.2c)	medium
	Retardation	7.2.5.5	medium
	Calorimetric	7.3.3c)	low/medium

6 Common determinations

These determinations are applicable to more than one of the listed methods.

6.1 Efficiency

Efficiency is:

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

where

- P_1 is the input power excluding excitation power from a separate source;
- P_2 is the output power;
- P_{1E} is the excitation power supplied by a separate source;
- P_T is the total loss according to 6.2.

NOTE 1 Input power P_1 and output power P_2 are as follows:

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

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

NOTE 2 P_T includes the excitation power P_e of the machine where applicable.

6.2 Total loss

When the total loss is determined as the sum of the separate losses the following formulae apply:

For direct current machines:

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

1 If the relative error in P_{irs} (see 7.3.1) is likely to be greater than 3 %, the calorimetric method is not recommended.

$$P_e = P_f + P_E$$

$$P_k = P_{fw} + P_{Fe}$$

For induction machines:

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

$$P_k = P_{fw} + P_{Fe}$$

For synchronous machines:

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

$$P_e = P_f + P_E + P_b$$

$$P_k = P_{fw} + P_{Fe}$$

where:

- P_a is the I^2R armature-winding loss (interpole, compensation and series field winding loss in case of d.c. machines),
- P_b is the brush loss,
- P_E is the exciter loss,
- P_e is the excitation power,
- P_f is the excitation (field winding) loss,
- P_{Fe} is the iron loss,
- P_{fw} is the friction and windage loss,
- P_k is the constant loss,
- P_{LL} is the additional load loss,
- P_r is the I^2R rotor winding loss,
- P_s is the stator I^2R winding loss,
- P_T is the total loss.

6.3 Load losses

Losses relative to machine load (with lowest uncertainty) are best determined from actual measurements. For example: measurements of current, resistance, etc. under full-load operation.

When this is not possible, these values shall be obtained from calculation of the parameters during the design stage.

Determination of losses not itemized in this part may be found in IEC 60034-2-1.

7 Methods

For the determination of performance when machine load and/or size exceed test capabilities (described in IEC 60034-2-1), the following test methods may be used.

NOTE These methods are generally applicable to large machines where the facility cost for other methods is not economical.

7.1 Calibrated machine method

The calibrated machine method may be used to determine the test machine efficiency either directly or by separate losses.

7.1.1 General

This method is generally applied as a factory test.

This method requires a calibrated machine mechanically coupled to the machine under test and is used when neither a torque meter nor dynamometer is available. The mechanical input of the tested machine is calculated from the electrical input of the calibrated machine.

7.1.2 Machine calibration

When a gear-box is directly connected to the machine it shall be considered as part of the calibrated machine.

Calibrate an electric machine, preferably a direct-current machine, according to one of the procedures in IEC 60034-2-1 at a sufficient number of thermally stable loads (including no-load) to determine an accurate relationship of output power as a function of input power adjusted for the temperature of the cooling air/medium at inlet. This is generally developed in the form of a curve.

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

7.1.3 Test procedure

The tested machine shall be equipped with winding ETDs.

The tested machine shall be completely assembled with essential components as for normal operation.

Before starting the test, record the winding resistances and the ambient temperature.

The machine for which the performance is to be determined shall be mechanically coupled to the calibrated machine and be operated at a speed equivalent to its synchronous/rated speed.

Operate the calibrated machine with the test machine at either rated-load, partial-load; no-load not excited, with or without brushes; no-load excited at rated voltage; or short-circuited, which enables specific categories of losses to be determined.

When the test machine is operated at each specified test condition and has reached thermal stability, record:

NOTE The following example represents testing with a motor as the calibrated machine.

- for the calibrated machine

  P_1 = power

  U_1 = input voltage

  I_1 = current

  θ_{1c} = temperature of inlet cooling air

  θ_{1w} = winding temperature (by variation of resistance if possible)

  n_1 = speed

- for the test machine (direct determination as a generator)

  P_2 = output power

U_2 = output voltage

I_2 = armature load current

θ_{2w} = windings temperature (either directly by ETDs or by resistance variation)

n_2 = speed

– for the unloaded test machine (as a generator)

U_2 = armature voltage (when excited open-circuit)

I_2 = armature current (when excited short-circuit)

θ_{2w} = windings temperature (either directly by ETDs or by resistance variation)

n_2 = speed

Upon completion of each test, stop the machines and record in the given order:

– test machine winding resistance;
– calibrated machine winding resistance.

Finally operate the calibrated machine without electrical connection to the test machine and record as specified above.

7.1.4 Determination of performance

From the curve developed in 7.1.2 and using the calibrated machine input values, select the appropriate output power to the test machine.

Adjust the output power for the standardized coolant temperature.

Determination of excitation power shall be in accordance with IEC 60034-2-1.

7.1.4.1 Direct efficiency determination

When tested according to 7.1.3 the test machine efficiency is:

$$\eta = \frac{P_2}{P_1}$$ test machine working as a generator, calibrated machine working as a motor

where

P_2 is the output power of test generator

P_1 is the calculated input power to the test generator according to 7.1.3.

and:

$$\eta = \frac{P_2}{P_1}$$ test machine working as a motor, calibrated machine working as a generator

where

P_1 is the input power to test motor

P_2 is the calculated output power from the test motor.

7.1.4.2 Separate losses

Using values of P determined from the calibrated machine curve, it is possible to determine the power dissipated by the test machine for other selected conditions that may be used to determine efficiency according to 6.1.

a) Friction and windage loss at rated speed (when the test machine is not electrically connected);

b) Active iron loss, and additional open-circuit losses in d.c. and synchronous machines, (when tested at no-load, open-circuit, excited at rated voltage, minus the windage and friction loss). Field losses from a separate source;

c) Armature-winding loss and additional-load loss in synchronous machines, (when tested under short-circuit conditions, excited at rated armature current, minus the windage and friction loss). Field losses from a separate source.

7.2 Retardation method

The retardation method can be used in determining the separate losses of rotating electrical machines having an appreciable rotational inertia.

The retardation method is used to determine:

– sum of the friction loss and windage loss ("mechanical losses") in machines of all types;

– sum of losses in active iron and additional open-circuit losses in d.c. and synchronous machines;

– sum of I^2R losses in an operating winding and additional-load losses ("short-circuit losses") in synchronous machines.

7.2.1 Fundamentals

The recorded test loss P_t which retards the machine is proportional to the product of the speed at which this loss corresponds and the deceleration at that speed:

$$P_t = -Cn\frac{dn}{dt}$$

where:

P_t is the loss being measured, W;

C is the retardation constant according to 7.2.4;

n is the speed, min^{-1};

dn/dt is the deceleration from 7.2.3.

NOTE The accuracy of the retardation method is directly related to the accuracy of the retardation constant C which depends solely on the moment of inertia J (see 7.2.4).

7.2.2 Test procedure

7.2.2.1 Assembly of test machine

The test machine shall be assembled, with all essential components, as for normal operation, but uncoupled from other rotating parts. A suitable speed sensor shall be attached to the rotating element.

NOTE When the machine cannot be uncoupled, all possible steps should be taken to reduce the mechanical losses in other rotating parts, e.g. by partial dismantling or in the case of a water turbine, by preventing water in the runner chamber. Rotation of the runner in air produces a windage loss which should be determined either experimentally or from calculations.

7.2.2.2 Machine preparation for test

Electrically connect the test machine as a motor (on no-load) fed from a separate power source having a wide range of variable frequency. Any excitation shall be obtained from a separate source with a rapid and precise voltage control.

NOTE 1 The test machine may be driven by its normal prime mover, e.g. by Pelton turbine when the water supply to the runner can be cut off instantly.

NOTE 2 Excitation from a mechanically-coupled exciter is not recommended, but may be permitted when the value of the deviation of speed δ does not exceed 0,05. Losses in exciters coupled to the shaft of the test machine are to be taken into account.

The bearing temperatures shall be adjusted to the normal temperature at which the bearings operate with rated load, by adjusting the coolant flow.

The air temperature shall be adjusted, whenever possible, to the normal temperature at which the windage loss measurement is required by throttling the air coolant flow.

7.2.2.3 Testing preparation

Retardation tests shall be conducted as a series without interruption, whenever possible. It is recommended that the series start and finish with retardation tests of the test machine unexcited.

All tests shall be repeated several times at the preset rated values of open-circuit voltage or short-circuit current. The arithmetic mean value obtained from each series of measurements shall be assumed to be the appropriate loss value of that category of loss.

Select a value of δ (the per unit deviation of rotational speed from rated speed) which shall not be greater than 0,1 and may have to be less than this, depending on the characteristics of the machine.

7.2.2.4 Tests

Rapidly accelerate the test machine to a speed above n_N (1 + δ). Disconnect the machine from its supply source. Sufficient time delay shall separate the switching off of the supply and starting the measurements to allow electromagnetic transients to decay.

During deceleration to n_N (1 – δ) place the test machine in the required condition, according to the following tests:

When moment of inertia is known.

a) running unexcited;
b) running open-circuited, excited at rated voltage;
c) running with the armature terminals short-circuited, and the excitation set to give the rated armature current.

NOTE As an alternate, tests may be carried out at various values within limits of the order of 95 % to 105 % of either the rated voltage or rated short-circuit current.

Additional tests, when the moment of inertia is unknown, shall be conducted at the same values as determined in b) and c) according to either d) e) or f).

d) with the field suppressed, connect the test machine to a transformer previously set under no-load condition and excited to the preset values of current or open-circuit voltage;
e) with the field suppressed, connect the test machine to a transformer previously set under short-circuit;
f) with the field suppressed, simultaneously load the exciter or the auxiliary generator with a ballast resistance at a predetermined load.

Each retardation test shall be repeated at least twice.