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INTERNATIONAL STANDARD

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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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ROTATING ELECTRICAL MACHINES –

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

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

This second edition cancels and replaces the first edition of IEC 60034-2-1, issued in 2007, as well as IEC 60034-2A, issued in 1974. This edition constitutes a technical revision.

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

a) The test methods are now grouped into preferred methods and methods for field or routine testing. Preferred methods have a low uncertainty and for a specific rating and type of machine only one preferred method is now defined.
b) The requirements regarding instrumentation have been detailed and refined.
c) The description of tests required for a specific method is now given in the same sequence as requested for the performance of the test. This will avoid misunderstandings and

improve the accuracy of the procedures. In addition, for each method a flowchart shows the sequence of tests graphically.

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

FDIS	Report on voting
2/1742/FDIS	2/1748/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.

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ROTATING ELECTRICAL MACHINES –

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

1 Scope

This part of IEC 60034 is intended to establish methods of determining efficiencies from tests, and also to specify methods of obtaining specific losses.

This standard applies to d.c. machines and to a.c. synchronous and induction machines of all sizes within the scope of IEC 60034-1.

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

2 Normative references

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

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IEC 60027-1, *Letter symbols to be used in electrical technology – Part 1: General*

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IEC 60034-1:2010, *Rotating electrical machines – Part 1: Rating and performance*

IEC 60034-4:2008, *Rotating electrical machines – Part 4: Methods for determining synchronous machine quantities from tests*

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

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

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.

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
dynamometer
device for measuring torque applied to the rotating part of the machine under test. It is equipped with means for measuring and indicating torque and speed, and is not limited to a cradle base construction. An in-line torque transducer may be used to provide a direct measurement of torque at the shaft of the machine under test.

3.4
dynamometer test
test in which the mechanical power output of a machine acting as a motor is determined by a dynamometer. Also a test in which the mechanical input power of a machine acting as a generator is determined by a dynamometer.

3.5
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

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3.6
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.

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3.7
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.

3.8
no-load test
test in which a machine is run as a motor providing no useful mechanical output from the shaft, or when run as a generator with its terminals open-circuited

3.9
zero power factor test (synchronous machines)
no-load test on a synchronous machine, which is over-excited and operates at a power factor very close to zero

3.10
equivalent circuit method (induction machines)
test in which the losses are determined by help of an equivalent circuit model

3.11
test with rotor removed and reverse rotation test (induction machines)
combined test in which the additional load losses are determined from a test with rotor removed and a test with the rotor running in reverse direction to the rotating magnetic field of the stator

3.12
short-circuit test (synchronous machines)
test in which a machine is run as a generator with its terminals short-circuited

3.13
locked rotor test
test in which the rotor is locked to prevent rotation

3.14
eh-star test
test in which the motor is run in star connection on unbalanced voltage

3.15 Losses

3.15.1
total losses
P_T
difference between the input power and the output power, equivalent to the sum of the constant losses (see 3.15.2), the load losses (see 3.15.4), the additional load losses (see 3.15.5) and the excitation circuit losses (see 3.15.3)

3.15.2
constant losses
losses incorporating the sum of windage, friction and iron losses. Although these losses change with voltage and load, they are historically called “constant” losses and the name is retained in this standard.

3.15.2.1
constant losses
P_c
sum of the iron losses and the friction and windage losses

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3.15.2.2
iron losses
P_{fe}
losses in active iron and additional no-load losses in other metal parts

3.15.2.3 Friction and windage losses P_{fw}

3.15.2.3.1
friction losses
losses due to friction (bearings and brushes, if not lifted at rated conditions) not including any losses in a separate lubricating system

3.15.2.3.2
windage losses
total losses due to aerodynamic friction in all parts of the machine, including power absorbed in shaft mounted fans, and in auxiliary machines forming an integral part of the machine

Note 1 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.

3.15.3 Excitation circuit losses

3.15.3.1
excitation circuit losses
P_e
sum of the excitation winding losses (see 3.15.3.2), the exciter losses (see 3.15.3.3) and, for synchronous machines, electrical brush loss (see 3.15.3.5), if any

3.15.3.2
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

3.15.3.3
exciter losses
P_{Ed}
the exciter losses for the different excitation systems (see Annex B) are defined as follows:

a) Shaft driven exciter

The exciter losses are the power absorbed by the exciter at its shaft (reduced by friction and windage losses) plus the power P_{1E} drawn from a separate source at its excitation winding terminals, minus the useful power which the exciter provides at its terminals. The useful power at the terminals of the exciter is equal to the excitation winding losses as per 3.15.3.2 plus (in the case of a synchronous machine) the electrical brush losses as per 3.15.3.5.

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.

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

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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.

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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.

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 3.15.3.2 and 3.15.3.4. 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 3.15.3.2 and 3.15.3.4.

Note 3 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 4 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 (d.c. machine).

If the excitation is supplied by a system having components as described in b) to e) the exciter losses shall include the relevant losses of the components pertaining to the categories listed in Annex B as applicable.

3.15.3.4
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 (d.c. or synchronous exciter) or stator winding input power (induction exciter). It covers a part of the exciter losses P_{Ed} (and further losses in induction exciters) while a larger part of P_e is supplied via the shaft;
– for exciter types c) and d) equal to the excitation circuit losses, $P_{1E} = P_e$;
– for exciter type e) $P_{1E} = 0$, the excitation power being delivered entirely by the shaft. Also, $P_{1E} = 0$ for machines with permanent magnet excitation.

Exciter types shall be in accordance with 3.15.3.3.

3.15.3.5
brush losses (excitation circuit)
P_b

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

3.15.4 Load losses

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3.15.4.1
load losses
P_L
sum of the winding (I^2R) losses (see 3.15.4.2) and the electrical brush losses (see 3.15.4.3), if any

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3.15.4.2
winding losses
winding losses are I^2R losses:

– in the armature circuit of d.c. machines;
– in the stator and rotor windings of induction machines;
– in the armature and field windings of synchronous machines

3.15.4.3
brush losses (load circuits)
P_b

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

3.15.5
additional load losses (stray-load losses)
P_{LL}
losses produced in active iron and other metal 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 These losses do not include the additional no-load losses of 3.15.2.2.

3.15.6
short-circuit losses
$\boldsymbol{P}_{\mathbf{k}}$
current-dependent losses in a synchronous machine and in a d.c. machine when the armature winding is short-circuited

3.16 Test quantities (polyphase a.c. machines)

3.16.1
terminal voltage
for polyphase a.c. machines, the arithmetic average of line voltages

3.16.2
line current
for polyphase a.c. machines, the arithmetic average of line currents

3.16.3
line-to-line resistance
for polyphase a.c. 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.

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3.16.4
temperature rise
is the machine temperature minus the cooling medium (coolant) temperature as defined by IEC 60034-1

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4 Symbols and abbreviations

4.1 Symbols

$\cos \varphi$ is the power factor[1]

f is the supply frequency, Hz

I is the average line current, A

k_θ is the temperature correction factor

n is the operating speed, s^{-1}

p is the number of pole pairs

P is the power, W

P_0 is the input power at no-load, W

P_1 is the input power, excluding excitation[2], W

P_2 is the output power, W

P_b is the brush loss, W

P_e is the excitation circuit losses, W

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

P_{Ed} is the exciter losses, W

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1 This definition assumes sinusoidal voltage and current.

2 Unless otherwise indicated, the tests in this standard are described for motor operation, where P_1 and P_2 are electrical input and mechanical output power, respectively.

P_{el} is the electrical power, excluding excitation, W

P_f is the excitation (field) winding losses, W

P_{fe} is the iron losses, W

P_{fw} is the friction and windage losses, W

P_c is the constant losses, W

P_L is the load losses, W

P_{Lr} is the residual losses, W

P_{LL} is the additional-load losses, W

P_{mech} is the mechanical power, W

P_k is the short-circuit losses, W

P_T is the total losses, W

P_w is the winding losses, W, where subscript w is generally replaced by a, f, e, s or r (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 6.4.5.5), Ω

R'_{eh} is the typical value of the auxiliary resistor, Ω

R_f is the field winding resistance, Ω

R_{ll} is the average line-to-line-resistance, Ω

R_{ph} is the average phase-resistance, Ω

s is the slip, in per unit value of synchronous speed

T is the machine torque, N·m

T_d is the reading of the torque measuring device, N·m

T_c is the torque correction, N·m

U is the average terminal voltage, V

U_0 is the terminal voltage at no-load, V

U_N is the rated terminal voltage, V

X is the reactance, Ω

$\underline{Z} = R + j \times X$ is the notation for a complex quantity (impedance as example)

$Z = |\underline{Z}| = \sqrt{R^2 + X^2}$ is the absolute value of a complex quantity (impedance as example)

Z is the impedance, Ω

η is the efficiency

θ_0 is the initial winding temperature, °C

θ_a is the ambient temperature, °C

θ_c primary coolant inlet temperature, °C

θ_w is the winding temperature, °C

τ is a time constant, s

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https://standards.iteh.ai/catalog/standards/sist/1a72aba6-065a-4d42-95b2-32d7c83d6a65/iec-60034-2-1-2014

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