



# UL 60034-2-1

## STANDARD FOR SAFETY

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

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UL Standard for Safety for Rotating Electrical Machines – Part 2-1: Standard methods for determining losses and efficiency from tests (excluding machines for traction vehicles) (IEC 60034-2-1:2014, IDT), UL 60034-2-1

First Edition, Dated February 21, 2017

### **Summary of Topics**

***This revision of ANSI/UL 60034-2-1 dated March 30, 2022 is being issued to update the title page to reflect the most recent designation as a Reaffirmed American National Standard (ANS). No technical changes have been made.***

***UL 60034-2-1 is an adoption of IEC 60034-2-1, Rotating Electrical Machines – Part 2-1: Standard methods for determining losses and efficiency from tests (excluding machines for traction vehicles) (Second Edition, issued June 2014). Please note that there are no National Differences.***

Text that has been changed in any manner or impacted by UL's electronic publishing system is marked with a vertical line in the margin.

The requirements are substantially in accordance with Proposal(s) on this subject dated January 21, 2022.

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**ANSI/UL 60034-2-1-2017 (R2022)**

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**UL 60034-2-1**

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

**First Edition**

**February 21, 2017**

This ANSI/UL Standard for Safety consists of the First Edition including revisions through March 30, 2022.

The most recent designation of ANSI/UL 60034-2-1 as a Reaffirmed American National Standard (ANS) occurred on March 21, 2022. ANSI approval for a standard does not include the Cover Page, Transmittal Pages, Title Page, or Preface. The IEC Foreword is also excluded from the ANSI approval of IEC-based standards.

Comments or proposals for revisions on any part of the Standard may be submitted to UL at any time. Proposals should be submitted via a Proposal Request in UL's On-Line Collaborative Standards Development System (CSDS) at <https://csds.ul.com>.

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## Preface (UL)

This UL Standard is based on IEC Publication 60034-2-1: second edition, Rotating electrical machines – Part 2-1: Standard methods for determining losses and efficiency from tests (excluding machines for traction vehicles). IEC publication 60034-2-1 is copyrighted by the IEC.

This UL Standard 60034-2-1, Standard for Safety for Rotating Electrical Machines – Part 2-1: Standard methods for determining losses and efficiency from tests (excluding machines for traction vehicles), is to be used in conjunction with the First Edition of UL 60034-1. The requirements are therefore contained in this Part 2 Standard and UL 60034-1.

Requirements of this Part 2 Standard, where stated, amend the requirements of UL 60034-1.

Where a particular subclause of UL 60034-1 is not mentioned in UL 60034-2-1, the UL 60034-1 subclause applies.

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**Note – Although the intended primary application of this Standard is stated in its Scope, it is important to note that it remains the responsibility of the users of the Standard to judge its suitability for their particular purpose.**

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# FOREWORD

## INTERNATIONAL ELECTROTECHNICAL COMMISSION

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

1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.

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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.

The committee has decided that the contents of this 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.

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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.

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

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

## 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.

## 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

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

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 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

#### 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

#### 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** $P_k$ 

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  $\Delta$ -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.

## 3.16.4

**temperature rise**

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

**4 Symbols and abbreviations****4.1 Symbols**

$\cos \varphi$  is the power factor<sup>1</sup>

$f$  is the supply frequency, Hz

$I$  is the average line current, A

$k_{\theta}$  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<sup>2</sup>, W

$P_2$  is the output power, W

$P_b$  is the brush loss, W

$P_e$  is the excitation circuit losses, W

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

$P_{Ed}$  is the exciter losses, W

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

$P_f$  is the excitation (field) winding losses, W

$P_{fe}$  is the iron losses, W

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

$P_c$  is the constant losses, W

$P_L$  is the load losses, W

$P_{Lr}$  is the residual losses, W

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

$P_{mech}$  is the mechanical power, W

$P_k$  is the short-circuit losses, W

$P_T$  is the total losses, W

$P_w$  is the winding losses, W, where subscript w is generally replaced by a, f, e, s or r (see [4.2](#))

$R$  is a winding resistance,  $\Omega$

$R_{eh}$  is the actual value of the auxiliary resistor for the Eh-star test (see 6.4.5.5),  $\Omega$

$R'_{eh}$  is the typical value of the auxiliary resistor,  $\Omega$

$R_f$  is the field winding resistance,  $\Omega$

$R_{ll}$  is the average line-to-line-resistance,  $\Omega$

$R_{ph}$  is the average phase-resistance,  $\Omega$

$s$  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,  $N \cdot m$

$T_c$  is the torque correction,  $N \cdot m$

$U$  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,  $\Omega$

$$\underline{Z} = R + j \times X$$

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,  $\Omega$

$\eta$  is the efficiency

$\theta_0$  is the initial winding temperature,  $^{\circ}C$

$\theta_a$  is the ambient temperature,  $^{\circ}C$

$\theta_c$  primary coolant inlet temperature,  $^{\circ}C$

$\theta_w$  is the winding temperature,  $^{\circ}C$

$\tau$  is a time constant,  $s$

<sup>1</sup> This definition assumes sinusoidal voltage and current.

<sup>2</sup> 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.

## 4.2 Additional subscripts

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

Machine components:

- a armature
- e excitation
- f field winding
- r rotor
- s stator
- w winding

U,V,W phase designations

Machine categories:

- B booster
- D dynamometer
- E exciter
- G generator
- M motor

Operating conditions:

- 0 no-load
- 1 input
- 2 output
- av average, mean
- d dissipated
- el electrical
- i internal
- k short circuit
- L test load

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lr locked rotor

mech mechanical

N rated

red at reduced voltage

t test

zpf zero power factor test

$\theta$  corrected to a reference coolant temperature.

NOTE Further additional subscripts are introduced in relevant subclauses.

## 5 Basic requirements

### 5.1 Direct and indirect efficiency determination

Tests can be grouped into the three following categories:

- a) input-output 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;
- b) 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;
- c) 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 should 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, fieldtests 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 60034-1:2010.

### 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 equipment manufacturer. If appropriate, temperature corrections according to the equipment manufacturer's specification shall be made.

Digital instruments shall be used whenever possible.

For analog 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 equipment, particularly the current sensors, shall be adapted to the power of the machine under test.

For analog 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 samples (typically many hundred samples) shall be taken automatically by a suitable digital meter over a period of several fluctuation cycles but not more than 15 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 an 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 9.1 of IEC 60034-1, an accuracy class of 0,5 is sufficient.

In the case of a.c. 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 instrumentation used to measure the torque shall have a minimum class of 0,2. The minimum torque measured shall be at least 10 % of the torque meter's nominal torque. 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.