



UL 60034-2-1 (IEC 60034-2-1:2014)

STANDARD FOR SAFETY

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

*UL COPYRIGHTED MATERIAL –
NOT AUTHORIZED FOR FURTHER REPRODUCTION OR
DISTRIBUTION WITHOUT PERMISSION FROM UL*



Documents

Document Sharing Hub

*UL COPYRIGHTED MATERIAL –
NOT AUTHORIZED FOR FURTHER REPRODUCTION OR
DISTRIBUTION WITHOUT PERMISSION FROM*



Documents

Document Sharing Hub

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), UL 60034-2-1 (IEC 60034-2-1:2014)

First Edition, Dated February 21, 2017

Summary of Topics

This is the First Edition of UL 60034-2-1, the Standard for Rotating Electrical Machines – Part 2-1: Standard methods for determining losses and efficiency from tests (excluding machines for traction vehicles), which is an identical adoption of IEC 60034-2-1:2014.

The new requirements are substantially in accordance with Proposal(s) on this subject dated November 11, 2016.

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, or transmitted in any form by any means, electronic, mechanical photocopying, recording, or otherwise without prior permission of UL.

UL provides this Standard “as is” without warranty of any kind, either expressed or implied, including but not limited to, the implied warranties of merchantability or fitness for any purpose.

In no event will UL be liable for any special, incidental, consequential, indirect or similar damages, including loss of profits, lost savings, loss of data, or any other damages arising out of the use of or the inability to use this Standard, even if UL or an authorized UL representative has been advised of the possibility of such damage. In no event shall UL’s liability for any damage ever exceed the price paid for this Standard, regardless of the form of the claim.

Users of the electronic versions of UL’s Standards for Safety agree to defend, indemnify, and hold UL harmless from and against any loss, expense, liability, damage, claim, or judgment (including reasonable attorney’s fees) resulting from any error or deviation introduced while purchaser is storing an electronic Standard on the purchaser’s computer system.

No Text on This Page

February 21, 2017



1

ANSI/UL 60034-2-1-2017

UL 60034-2-1 (IEC 60034-2-1:2014)

**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.

The most recent designation of ANSI/UL 60034-2-1 (IEC 60034-2-1:2014) as an American National Standard (ANSI) occurred on February 17, 2017. 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>.

UL's Standards for Safety are copyrighted by UL. Neither a printed nor electronic copy of a Standard should be altered in any way. All of UL's Standards and all copyrights, ownerships, and rights regarding those Standards shall remain the sole and exclusive property of UL.

COPYRIGHT © 2017 UNDERWRITERS LABORATORIES INC.

**UL COPYRIGHTED MATERIAL –
NOT AUTHORIZED FOR FURTHER REPRODUCTION OR
DISTRIBUTION WITHOUT PERMISSION FROM UL**



Documents
Document Sharing Hub

No Text on This Page

**UL COPYRIGHTED MATERIAL –
NOT AUTHORIZED FOR FURTHER REPRODUCTION OR
DISTRIBUTION WITHOUT PERMISSION FROM UL**



Documents

Document Sharing Hub

CONTENTS

Preface (UL)	6
FOREWORD	7
1 Scope	9
2 Normative references	9
3 Terms and definitions	9
4 Symbols and abbreviations	15
4.1 Symbols	15
4.2 Additional subscripts	18
5 Basic requirements	19
5.1 Direct and indirect efficiency determination	19
5.2 Uncertainty	20
5.3 Preferred methods and methods for customer-specific acceptance tests, field-tests or routine-tests	20
5.4 Power supply	20
5.5 Instrumentation	20
5.6 Units	22
5.7 Resistance	22
5.8 State of the machine under test and test categories	24
5.9 Excitation circuit measurements	25
5.10 Ambient temperature during testing	26
6 Test methods for the determination of the efficiency of induction machines	26
6.1 Preferred testing methods	26
6.2 Testing methods for field or routine-testing	48
7 Test methods for the determination of the efficiency of synchronous machines	75
7.1 Preferred testing methods	75
7.2 Testing methods for field or routine testing	89
8 Test methods for the determination of the efficiency of d.c. machines	103
8.1 Testing methods for field or routine testing	103

**UL COPYRIGHTED MATERIAL –
NOT AUTHORIZED FOR FURTHER REPRODUCTION OR
DISTRIBUTION WITHOUT PERMISSION FROM UL**



Documents
Document Sharing Hub

Annex A (normative)

Calculation of values for the Eh-star method

Annex B (informative)

Types of excitation systems

Annex C (informative)

Induction machine slip measurement

Annex D (informative) Test report template for method 2-1-1B

Bibliography

**UL COPYRIGHTED MATERIAL –
NOT AUTHORIZED FOR FURTHER REPRODUCTION OR
DISTRIBUTION WITHOUT PERMISSION FROM UL**



Documents

Document Sharing Hub

No Text on This Page

*UL COPYRIGHTED MATERIAL –
NOT AUTHORIZED FOR FURTHER REPRODUCTION OR
DISTRIBUTION WITHOUT PERMISSION FROM UL*



Documents

Document Sharing Hub

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.

The text, figures and tables of IEC Publication Rotating electrical machines – Part 2-1: Standard methods for determining losses and efficiency from tests (excluding machines for traction vehicles), 60034-2-1, copyright 2014-06, are used in this Standard with the consent of the IEC and the American National Standards Institute (ANSI). The IEC copyrighted material has been reproduced with permission from ANSI. ANSI should be contacted regarding the reproduction of any portion of the IEC material. The IEC Foreword and Introduction are not a part of the requirements of this Standard but are included for information purposes only. Copies of IEC Publication 60034-2-1 may be purchased from ANSI, 11 West 42nd Street, New York, New York, 10036, (212) 642-4900.

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.

UL COPYRIGHTED MATERIAL –
NOT AUTHORIZED FOR FURTHER REPRODUCTION OR
DISTRIBUTION WITHOUT PERMISSION FROM



Documents

Document Sharing Hub

INTERNATIONAL ELECTROTECHNICAL COMMISSION

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

FOREWORD

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 nongovernmental 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.

2) The formal decisions or agreements of IEC on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested IEC National Committees.

3) IEC Publications have the form of recommendations for international use and are accepted by IEC National Committees in that sense. While all reasonable efforts are made to ensure that the technical content of IEC Publications is accurate, IEC cannot be held responsible for the way in which they are used or for any misinterpretation by any end user.

4) In order to promote international uniformity, IEC National Committees undertake to apply IEC Publications transparently to the maximum extent possible in their national and regional publications. Any divergence between any IEC Publication and the corresponding national or regional publication shall be clearly indicated in the latter.

5) IEC itself does not provide any attestation of conformity. Independent certification bodies provide conformity assessment services and, in some areas, access to IEC marks of conformity. IEC is not responsible for any services carried out by independent certification bodies.

6) All users should ensure that they have the latest edition of this publication.

7) No liability shall attach to IEC or its directors, employees, servants or agents including individual experts and members of its technical committees and IEC National Committees for any personal injury, property damage or other damage of any nature whatsoever, whether direct or indirect, or for costs (including legal fees) and expenses arising out of the publication, use of, or reliance upon, this IEC Publication or any other IEC Publications.

8) Attention is drawn to the Normative references cited in this publication. Use of the referenced publications is indispensable for the correct application of this publication.

9) Attention is drawn to the possibility that some of the elements of this IEC Publication may be the subject of patent rights. IEC shall not be held responsible for identifying any or all such patent rights.

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.

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 Δ -connected machines, the phase-resistance is 1,5 times the line-to-line resistance.

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

3.16.4

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 factor¹

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 excitation², W

P_2 is the output power, W

P_b is the brush loss, W

P_e is the excitation circuit losses, W

UL COPYRIGHTED MATERIAL –
NOT AUTHORIZED FOR FURTHER REPRODUCTION OR
DISTRIBUTION WITHOUT PERMISSION FROM UL



Documents

Document Sharing Hub

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, 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, $^{\circ}\text{C}$

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

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

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

τ is a time constant, s

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.

UL COPYRIGHTED MATERIAL –
NOT AUTHORIZED FOR FURTHER REPRODUCTION OR
DISTRIBUTION WITHOUT PERMISSION FROM UL



Documents
Document Sharing Hub

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

**UL COPYRIGHTED MATERIAL –
NOT AUTHORIZED FOR FURTHER REPRODUCTION OR
DISTRIBUTION WITHOUT PERMISSION FROM UL**



Documents
Document Sharing Hub

lr locked rotor

mech mechanical

N rated

red at reduced voltage

t test

zpf zero power factor test

θ corrected to a reference coolant temperature.

NOTE Further additional subscripts are introduced in relevant subclauses.

5 Basic requirements

5.1 Direct and indirect efficiency determination

Tests can be grouped into the three following categories:

- 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;
- b) 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.

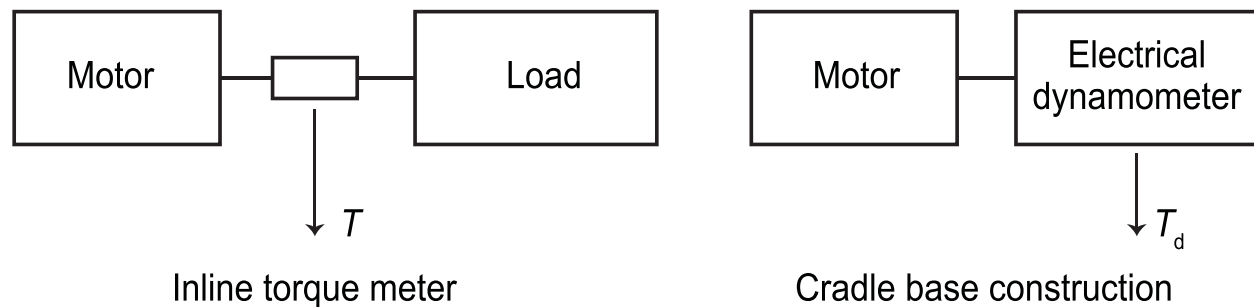
NOTE For a routine test as described in 9.1 of IEC 60034-1, an accuracy class of 0,5 is sufficient.

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.



su2523

When the shaft torque is measured by means of a dynamometer with a cradle base construction, a torque correction test shall be carried out to compensate the friction losses in the bearings of the loading machine. This also applies if any other bearing is interposed between the torque measuring device and the motor shaft.

The machine torque T is calculated using the formula:

$$T = T_d + T_c$$

Where

T_d is the torque reading of the load test;

T_c is the torque correction due to friction losses.

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

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

5.5.4 Speed and frequency measurement

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

NOTE 1 Speed in min^{-1} is n in $\text{s}^{-1} \times 60$.

NOTE 2 For asynchronous machines, the measurement of slip by a suitable method may replace speed measurement (see Annex C).

5.5.5 Temperature measurement

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

5.6 Units

Unless otherwise specified, the units of values are SI-units as listed in IEC 60027-1.

5.7 Resistance

5.7.1 Test resistance

Winding resistance R is the ohmic value, determined by appropriate methods.

For d.c. machines, R is the total resistance of all windings carrying armature current (armature, commutating, compensating winding, compound winding).

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

For polyphase a.c. machines, $R = R_{ll}$ is the line-to-line average resistance of the stator or armature winding according to 3.16.3. In the case of wound rotor induction machines, $R_{r,ll}$ is the rotor line-to-line average resistance.

The measured resistance at the end of the thermal test shall be determined in a similar way to the extrapolation procedure as described in 8.6.2.3.3 of IEC 60034-1, using the shortest possible time instead of the time interval specified in Table 5 therein, and extrapolating to zero.

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

5.7.2 Winding temperature

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

a) temperature determined from the rated load test resistance R_N by the extrapolation procedure as described in 5.7.1;

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

b) temperature measured directly by either ETD or thermocouple;

c) temperature determined according to a) on a duplicate machine of the same construction and electrical design;

d) when load capability is not available, determine operating temperature according to IEC 60034-29;

e) when the rated load test resistance R_N cannot be measured directly, the winding temperature shall be assumed to be equal to the reference temperature of the rated thermal class as given in Table 1.

Table 1 – Reference temperature

Thermal class of the insulation system	Reference temperature °C
130 (B)	95
155 (F)	115
180 (H)	135

If the rated temperature rise or the rated temperature is specified as that of a lower thermal class than that used in the construction, the reference temperature shall be that of the lower thermal class.

UL COPYRIGHTED MATERIAL –
NOT AUTHORIZED FOR FURTHER REPRODUCTION OR
DISTRIBUTION WITHOUT PERMISSION FROM UL



Documents
Document Sharing Hub

5.7.3 Correction to reference coolant temperature

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

(1)

$$k_{\theta} = \frac{235 + \theta_w + 25 - \theta_c}{235 + \theta_w}$$

where

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

θ_c is the inlet coolant temperature during test;

θ_w is the winding temperature according to 5.7.2.

The temperature constant 235 is for copper; this should be replaced by 225 for aluminium conductors.

For machines with water as the primary or secondary coolant, the water reference temperature shall be 25 °C according to Table 4 of IEC 60034-1:2010. Alternative values may be specified by agreement.

5.8 State of the machine under test and test categories

Tests shall be conducted on an assembled machine with the essential components in place, to obtain test conditions equal or very similar to normal operating conditions.

NOTE 1 It is preferable that the machine be selected randomly from series production without special considerations.

Externally accessible sealing elements may be removed for the tests, if an additional test on machines of similar design has shown that friction is insignificant after adequately long operation.

NOTE 2 Motors with bearings and/or internal seals which are known to have less friction after adequately long operation, can be subjected to a run in before test.

The sub-tests that make up a test procedure shall be performed in the sequence listed. It is not essential that the tests be carried out immediately one after another. However, if the sub-tests are performed with delay, then the specified thermal conditions shall be re-established prior to obtaining the test data.

For machines with adjustable brushes, the brushes shall be placed in the position corresponding to the specified rating. For induction motors with wound rotor having a brush lifting device, the brushes shall be lifted during tests, with the rotor winding short-circuited. For measurements on no-load, the brushes shall be placed in the neutral axis on d.c. machines.

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

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

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

Friction losses due to thrust load may be included by agreement.

If the tested machine uses direct flow cooling of the bearings, these losses are distributed between the tested machine and any other one coupled to it mechanically, such as a turbine, in proportion to the masses of their rotating parts. If there is no direct flow cooling, the distribution of bearing losses shall be determined from empirical formulae by agreement.

5.9 Excitation circuit measurements

Determination of voltage U_e and current I_e (see 3.15.3.2) depends on the configurations of the excitation system (see 3.15.3.3). Where applicable, test data shall be recorded according to the following:

a) for machines excited by shaft driven, separate rotating, static and auxiliary winding exciters (see 3.15.3.3 a), c), d) and e)), voltage U_e and current I_e are measured:

- at the excitation winding terminals of d.c. machines;
- at the field winding slip-rings of synchronous machines;

b) for machines excited by brushless exciters (see 3.15.3.3 b)), test data shall be recorded by either of the following methods:

- voltage U_e measured using auxiliary (provisional) slip-rings connected to the field winding ends. From the voltage and resistance R_e determine the field winding current.

$$I_e = \frac{U_e}{R_e} = \frac{U_f}{R_f}$$

The field winding resistance is to be measured after switching off the machine using the extrapolation procedure according to 5.7.1;

- voltage U_e and current I_e measured using power slip-rings suitable for direct measurement of field winding current.

NOTE The difference between U_e and U_f (voltage drop of brushes) is in practice almost negligible.

Voltages and currents shall be measured at stabilized temperatures.

The excitation circuit losses P_e are determined according to 7.1.3.2.1 (synchronous machines) or 8.1.3.2.1 (d.c. machines).

5.10 Ambient temperature during testing

The ambient temperature should be in the range of 15 °C to 30 °C for at least the last hour of the rated load thermal test and all subsequent tests and measurements.

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

6.1 Preferred testing methods

6.1.1 General

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

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

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

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

Table 2 – Induction machines: preferred testing methods

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

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

6.1.2.1 General

This is a test method in which the mechanical power P_{mech} of a machine is determined by measurement of the shaft torque and speed. The electrical power P_{el} of the stator is measured in the same test.

Input and output power are:

(2)

in motor operation: $P_1 = P_{\text{el}}$; $P_2 = P_{\text{mech}}$ (see Figure 1);

(3)

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

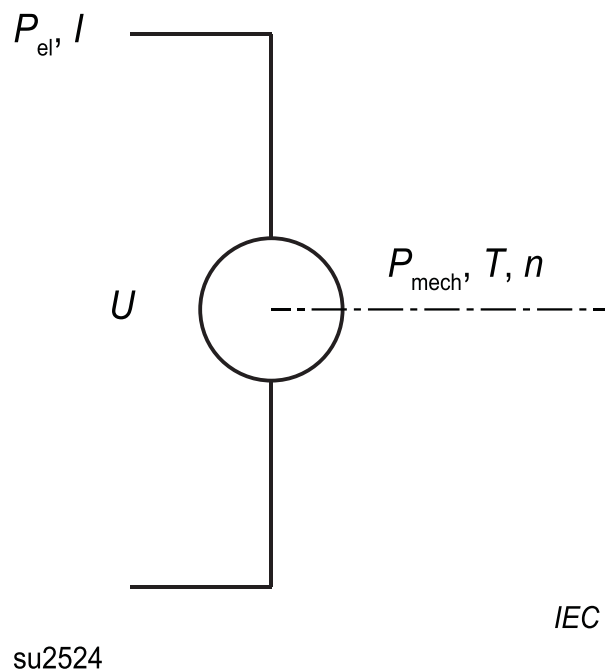


Figure 1 – Sketch for torque measurement test

For an overview, Figure 2 provides a flowchart for efficiency determination by this test method.

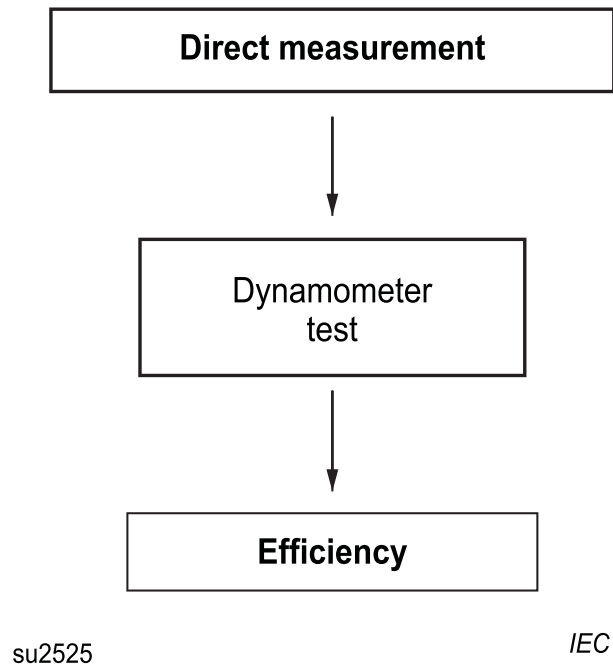


Figure 2 – Efficiency determination according to method 2-1-1A

6.1.2.2 Test procedure

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

Record U , I , P_{el} , n , T , θ_c .

6.1.2.3 Efficiency determination

The efficiency is:

(4)

$$\eta = \frac{P_2}{P_1}$$

Input power P_1 and output power P_2 are:

(5)

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

(6)

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

where

(7)

$$P_{mech} = 2\pi \times T \times n.$$

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

6.1.3.1 General

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

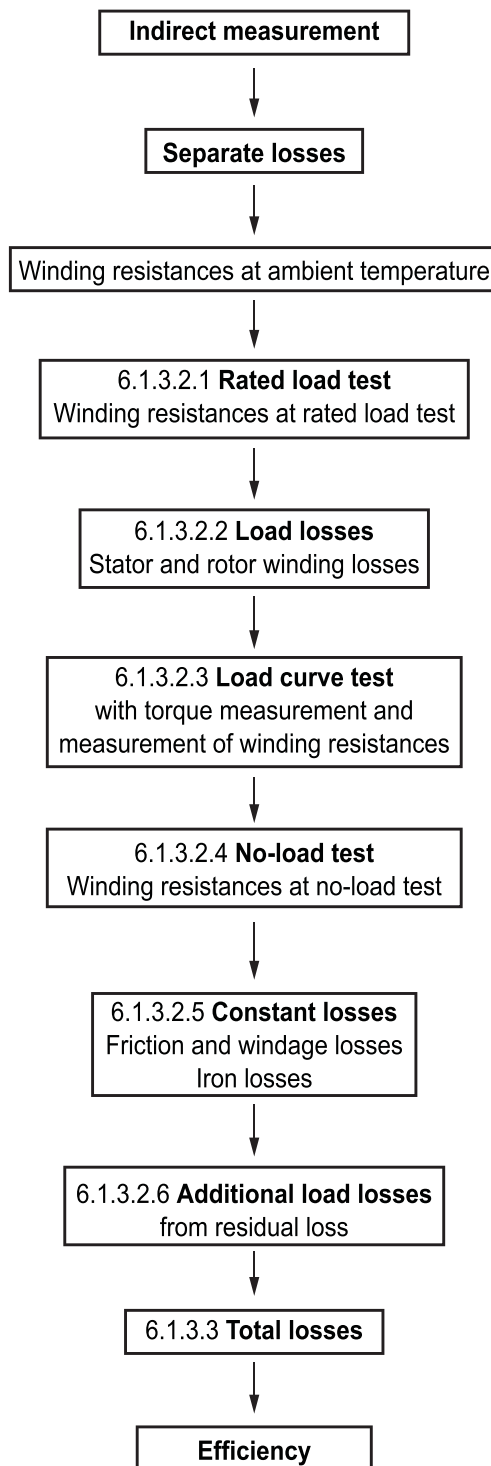
- iron loss;
- windage and friction losses;
- stator and rotor copper losses;
- additional load losses.

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

UL COPYRIGHTED MATERIAL –
NOT AUTHORIZED FOR FURTHER REPRODUCTION OR
DISTRIBUTION WITHOUT PERMISSION FROM UL



Documents
Document Sharing Hub



su2526

IEC

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

6.1.3.2 Test procedure

6.1.3.2.1 Rated load test

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

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

- P_1 , T , I , U , n , f , θ_c , θ ;
- $R_N = R$ (the test resistance for rated load according to 5.7.1);
- θ (the winding temperature at rated load according to 5.7.2).

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

6.1.3.2.2 Load losses

Stator-winding losses and temperature correction

The uncorrected stator-winding losses at rated load are:

(8)

$$P_s = 1,5 \times I^2 \times R$$

where I and R are determined in 6.1.3.2.1.

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

(9)

$$P_{s, \theta} = P_s \times k_\theta$$

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

Rotor winding losses and temperature correction

For the uncorrected rotor winding losses use the formula:

(10)

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

where

(11)

$$s = 1 - \frac{p \times n}{f}$$

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

P_s according to the load test as stated above;

P_{fe} is according to 6.1.3.2.5.

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

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

where

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

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

k_θ is the correction according to 5.7.3.

Temperature correction of input power (for a motor)

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

(12)

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

6.1.3.2.3 Load curve test

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

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

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

Supply frequency variation between all points shall be less than 0,1 %.

Measure R before the highest and after the lowest load reading. The resistance for 100 % load and higher loads shall be the value determined before the highest load reading. The resistance used for loads less than 100 % shall then be determined as varying linearly with load, using the reading before the test for the highest load and after the lowest reading for 25 % load.

NOTE Resistances may also be determined by measuring the stator winding temperature using a temperature-sensing device installed on the winding. Resistances for each load point may then be determined from the temperature of the winding at that point in relation to the resistance and temperature measured before the start of the test.

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

Stator-winding losses

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

(13)

$$P_s = 1,5 \times I^2 \times R$$

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

Rotor winding losses

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

(14)

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

where

(15)

$$s = 1 - \frac{p \times n}{f}$$

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

P_s according to the load curve test as stated above;

P_{fe} is according to 6.1.3.2.5.

6.1.3.2.4 No-load test

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

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

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

The test shall be carried out as quickly as possible with the readings taken in descending order of voltage.

Record at each of the voltage values: U_0 , I_0 , P_0

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

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

NOTE 1 For induction machines R_0 is $R_{ll,0}$. Where resistance measurement is impracticable due to very low resistances, calculated values are permissible.

NOTE 2 In a.c. machines, resistances may also be determined by measuring the stator winding temperature using a temperature-sensing device installed on the winding. Resistances for each voltage point may then be determined from the temperature of the winding at that point in relation to the resistance and temperature measured before the start of the test.

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

6.1.3.2.5 Constant losses

Subtracting the no-load winding losses from the no-load input power gives the constant losses that are the sum of the friction, windage and iron losses. Determine the constant losses for each value of voltage recorded.

(16)

$$P_c = P_0 - P_s = P_{fw} + P_{fe}$$

Where

(17)

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

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

Friction and windage losses

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

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

Iron losses

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

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

(18)

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

(19)

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

where

(20)

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

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

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

NOTE 1 The iron losses at full load may be calculated by using the ratio $(U_i/U_N)^2$ applied to the iron losses at no-load.

NOTE 2 Because the stator leakage inductance is unknown, the voltage is only considering the resistive voltage drop. Due to the low power factor at no-load, the resistive voltage drop is negligible during the measurement itself and shall only be taken into consideration for the load values.

6.1.3.2.6 Additional load losses P_{LL}

Residual losses P_{Lr}

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

(21)

$$P_{Lr} = P_1 - P_2 - P_s - P_r - P_{fe} - P_{fw};$$

(22)

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

where

(23)

$$P_{fw} = P_{fw0} \cdot (1 - s)^{2,5} \text{ with } s = 1 - \frac{p \times n}{f}$$

are the corrected friction and windage losses.

Smoothing of the residual loss data

The residual loss data shall be smoothed by using the linear regression analysis (see Figure 4) based on expressing the losses as a function of the square of the load torque according to the relationship:

(24)

$$P_{Lr} = A \times T^2 + B$$

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

(25)

A is the slope according to

UL COPYRIGHTED MATERIAL –
NOT AUTHORIZED FOR FURTHER REPRODUCTION OR
DISTRIBUTION WITHOUT PERMISSION FROM UL



Documents
Document Sharing Hub

$$A = \frac{i \cdot \sum (P_{Lr} \cdot T^2) - \sum P_{Lr} \cdot \sum T^2}{i \cdot \sum (T^2)^2 - (\sum T^2)^2}$$

(26)

B is the intercept according to

$$B = \frac{\sum P_{Lr}}{i} - A \cdot \frac{\sum T^2}{i}$$

i is the number of load points summed.

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

NOTE The intercept B may be positive or negative. Figure 4 shows an example for positive intercept B .

UL COPYRIGHTED MATERIAL –
NOT AUTHORIZED FOR FURTHER REPRODUCTION OR
DISTRIBUTION WITHOUT PERMISSION FROM UL



Documents

Document Sharing Hub

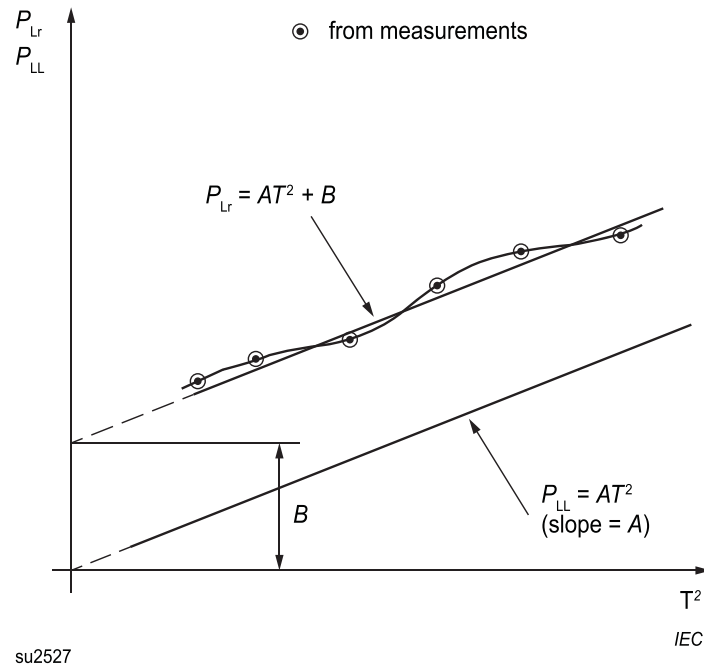


Figure 4 – Smoothing of the residual loss data

The correlation coefficient is calculated as

(27)

$$\gamma = \frac{i \times \sum (P_{Lr} \times T^2) - (\sum P_{Lr}) \times (\sum T^2)}{\sqrt{(i \times \sum (T^2)^2 - (\sum T^2)^2) \times (i \times \sum P_{Lr}^2 - (\sum P_{Lr})^2)}}$$

When the correlation coefficient γ is less than 0,95, delete the worst point and repeat the regression. If γ increases to $\geq 0,95$, use the second regression; if γ remains less than 0,95, the test is unsatisfactory and errors in the instrumentation or test readings, or both, are indicated. The source of the error should be investigated and corrected, and the test should be repeated. In case of sufficient test data, a correlation coefficient of 0,98 or better is likely.

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

(28)

$$P_{LL} = A \times T^2$$

UL COPYRIGHTED MATERIAL –
NOT AUTHORIZED FOR FURTHER REPRODUCTION OR
DISTRIBUTION WITHOUT PERMISSION FROM UL



Documents
Document Sharing Hub