

Rotating electrical machines —

Part 29: Equivalent loading and superposition techniques — Indirect testing to determine temperature rise

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National foreword

This British Standard is the UK implementation of EN 60034-29:2008. It is identical to IEC 60034-29:2008. It supersedes BS EN 61986:2002, which will be withdrawn on 1 June 2011.

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A list of organizations represented on this committee can be obtained on request to its secretary.

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**Rotating electrical machines -
Part 29: Equivalent loading and superposition techniques -
Indirect testing to determine temperature rise
(IEC 60034-29:2008)**

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Essais indirects pour déterminer
l'échauffement
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Drehende elektrische Maschinen -
Teil 29: Verfahren der äquivalenten
Belastung und Überlagerung -
Indirekte Prüfung zur Ermittlung
der Übertemperatur
(IEC 60034-29:2008)

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CENELEC

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Foreword

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Endorsement notice

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INTRODUCTION

The object of this standard is to provide various indirect load tests, the purpose of which is to determine the temperature rise of rotating electrical machines, including a.c. induction machines, a.c. synchronous machines and d.c. machines. The test methods in some cases provide, in addition, means of measuring or estimating other parameters such as losses and vibration, but the methods are not designed specifically to provide such data.

The proposed test methods are considered equivalent, the choice relying only on the location, the testing equipment and the machine type, and the test result accuracy.

This standard should not be interpreted as requiring any or all of the tests on any given machine. Particular tests are subject to a special agreement between the manufacturer and the purchaser.

NOTE As the methods reproduce only approximately the thermal conditions of the machines under rated condition, temperature-rise measurement results achieved from tests with these methods may be taken as the basis for the evaluation of machine heating in accordance with 8.10 of IEC 60034-1 by agreement between the manufacturer and the purchaser.

ROTATING ELECTRICAL MACHINES –

Part 29: Equivalent loading and superposition techniques – Indirect testing to determine temperature rise

1 Scope

This International Standard applies to machines covered by IEC 60034-1 when they cannot be loaded to a specific condition (rated or otherwise). It is applicable to both motors and generators.

2 Normative references

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

IEC 60034-1:2004, *Rotating electrical machines – Part 1: Rating and performance*

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

3 Symbols and units

For the purposes of this document, the following symbols and units apply.

K slope factor of temperature rise, K/W

NOTE 1 The full name of K is "slope factor of the straight line characterizing variation of temperature rise with losses", see IEC 60027-4, item 901.

$\Delta\theta$ temperature rise, K

θ temperature, °C

P power, loss, W

I current, A

R resistance, Ω

X reactance, Ω

U voltage, V

E e.m.f., V

f frequency, Hz

$f_{1,2}$ main/auxiliary frequency, Hz

Δt time interval, s

T torque, N·m

J moment of inertia, kg·m²

$\cos\varphi$ power factor

γ method uncertainty, %

NOTE 2 The definition implies that $\gamma > 0$ means test temperature rise is higher than at actual load condition.

δ_f	amplitude of frequency deviation, Hz
λ	ratio of auxiliary voltage to main voltage
σ	correction factor
ω	angular frequency, rad/s

Subscripts

m, n, o, p	test conditions
1, 2, 3, etc.	machine component (e.g. stator winding, rotor winding, stator core, etc.)

NOTE 3 If not indicated otherwise, numbers 1, 2, 3 will be used as assigned above.

t	test
f	field
a	ambient, referring to reference coolant (see IEC 60034-1, 8.2)
c	due to constant losses
L	leakage
N	rated value
equiv	equivalent-load test
super	superposition test

4 General test requirements

Measurement of the electrical parameters shall be made as follows.

- a) The class of accuracy of measuring instruments shall be not greater than 0,5.
- b) The measuring range of analogue instruments shall be chosen with a view to the measured values being higher than 30 % of the full-scale range. These requirements need not be complied with in the case of the three-phase power measurement by means of two wattmeters, but the currents and voltages in the measured circuits shall be at least 20 % of the rated currents and voltages of the wattmeters being used. The range of the other measuring instruments shall be chosen in such a way that the measuring errors are not increased.
- c) The waveform and symmetry of the supply voltage at the machine terminals shall be in accordance with the requirements of Clause 7 of IEC 60034-1.
- d) Each line current shall be measured. The arithmetic average value shall be used to determine the machine operating point.

NOTE When using the two-wattmeter method, it is acceptable to measure only two currents.

- e) Power input to a three-phase machine shall be measured by either two single-phase wattmeters connected as in the two-wattmeter method, or one polyphase wattmeter, or three single-phase wattmeters. The total power read on a wattmeter shall be reduced by the amount of the I^2R loss in the voltage circuits or in the current circuits of the instruments in accordance with their connection whenever this loss is a measurable portion of the total power.

Unless otherwise indicated all electrical quantities to be measured are root-mean-square values.

5 Superposition method

5.1 Basic principles

5.1.1 General

Superposition tests may be applied to any d.c. or a.c. machine. The method comprises a series of tests at operating conditions other than rated load, for example: reduced load, no load, short circuit, reduced voltage, positive (inductive) or negative (capacitive) reactive load.

The method allows the full-load temperature rise of various component parts of the machine to be deduced. For each component, the loss shall be known at each particular test condition and at full load. The machine should be tested with the same cooling conditions as when operating at rated load. Hence, a locked-rotor test will not be suitable as the air-flow distribution and magnitudes will be incorrect.

On completion of the individual tests, a series of equations based on equivalent thermal circuit theory is constructed, each equation being of the form:

$$\Delta\theta_{1m} = K_{11}P_{1m} + K_{12}P_{2m} + K_{13}P_{3m}$$

where

- $\Delta\theta_{1m}$ is the measured temperature rise of component 1 for test condition m;
- P_{1m}, P_{2m} etc. is the loss in component 1, 2, etc. for test condition m;
- $K_{11}, K_{12},$ etc. are the slope factors of temperature rise determining the temperature rise of component 1 due to losses in component 1, and the temperature rise of component 1 due to losses in component 2, etc.

Components 1, 2, and 3 may be, for example, the stator winding, the rotor winding, and the stator iron.

In some test conditions, certain losses may be equal to zero, and hence the related term in the equation disappears. For example, using the above assigned subscripts, a synchronous machine has $K_{11}P_1 = 0$ at no load and $K_{13}P_3 = 0$ at short circuit.

The method is based on the principle that the coefficients K do not change from test to test, i.e. that the cooling conditions are invariable between tests, which requires the speed to be the same in each test. The method is also based on the principle of linear thermal conditions so that temperature rises in one case can be added to those for another case. It requires the losses in the relevant component parts to be known with sufficient accuracy for each case, either by calculation or measurement.

When the tests have been completed and the equations compiled, the coefficients K can be derived by simple arithmetic. These are then used in a final equation with the losses for the rated load condition to calculate the temperature rise of component 1. By similar means, the temperature rises at rated load of components 2, 3, etc. can be derived.

If any component loss is temperature dependent (for example, stator copper loss), then the calculation procedure has to be repeated using values for the loss corrected for the estimated temperature rise. It is normally necessary to do this iteration once only. For the calculation of winding temperature rises corrected to a reference ambient temperature equations in closed form are also provided.

The method may be used to determine the temperature rise of any component at any load if the losses at that load are known. The slope factors of temperature rise (K_{12} , etc.) may be useful in other thermal modelling studies, for example, in analysing the response to supply unbalance, voltage reduction, etc.

In all superposition tests, correction is necessary for variation in heat exchanger performance (if one is fitted to the machine), as the thermal performance of the heat exchanger will partly depend on the total loss in each test.

5.1.2 Temperature rise

When determining the temperature rise values of machine parts by superposition tests, the variations from the results that should be obtained at rated-load test are always to be considered. The uncertainty value γ (%) for rated load is defined:

$$\gamma = \left(\frac{\Delta\theta_{N,\text{super}}}{\Delta\theta_N} - 1 \right) \times 100$$

NOTE 1 The uncertainty values obtained by superposition tests may be negative (test temperature rise is lower than under normal operation) or positive (test temperature rise is larger than under normal operation).

Consequently, for comparing with the temperature rise values given in IEC 60034-1, test results have to be multiplied with a correction factor σ :

$$\sigma = \frac{1}{1 + \frac{\gamma}{100}}$$

NOTE 2 For negative uncertainty values the correction factor is > 1 .

5.1.3 Estimation of temperature rise from reduced load tests

When estimating the temperature rise from tests at reduced load, the losses should be separated into variable (load) losses and constant (iron, friction and windage) losses. For the adjustment of temperature rise values, the machine may be considered as a two-component system (see 5.1.1).

NOTE Depending on the enclosure and pole number of the machine, the temperature rise due to the constant losses can be significant. Tests on large machines have shown that the separation of loss components results in better agreement between the reduced load estimation and the full load actual test.

When a load test is performed at currents different from rated current, the I^2R losses have to be converted to full load with the squared ratio of the currents, and the resistance R has to be corrected for total winding temperature. The following equation describes the adjustment of temperature rise to full load, neglecting the effect of constant losses and of additional load losses:

$$\Delta\theta_{1N} = \left(\frac{I_N}{I_{1t}} \right)^2 \cdot \Delta\theta_{1t} \cdot \left(\frac{235 + \theta_{at}}{235 + \theta_{at} + \Delta\theta_{1t} - \left(\frac{I_N}{I_{1t}} \right)^2 \cdot \Delta\theta_{1t}} \right)$$

where

I_N is the rated current;

I_{1t} is the measured stator current;

θ_{at} is the measured temperature of the reference coolant;

$\Delta\theta_{1t}$ is the measured stator winding temperature rise.

In cases where the portion of the winding temperature rise due to the constant losses is not known, and the total temperature rise is assumed due to I^2R losses only, the calculated temperature rise will be too large. Therefore, this method can be used only when the effect of constant losses is low; in most cases, methods taking constant and load losses separately into account are preferred. Induction machines are tested according to 5.2.2.