IEC 60216-6

Edition 3.0 2022-11
REDLINE VERSION

INTERNATIONAL STANDARD

colour inside

Electrical insulating materials – Thermal endurance properties – Part 6: Determination of thermal endurance indices (TI and ~~RTE~~ RTI) of an insulating material using the fixed time frame method



IEC 60216-6:2022-11 RLV(en)



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INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

ICS 17.220.99; 29.035.01

ISBN 978-2-8322-6173-6

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ELECTRICAL INSULATING MATERIALS – THERMAL ENDURANCE PROPERTIES –

Part 6: Determination of thermal endurance indices (TI and ~~RTE~~ RTI) of an insulating material using the fixed time frame method

FOREWORD

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IEC 60216-6 has been prepared by IEC technical committee 112: Evaluation and qualification of electrical insulating materials and systems. It is an International Standard.

This second edition cancels and replaces the first edition published in 2003. This edition constitutes a technical revision.

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

a) clarification of definition of index properties vs. endurance properties;

b) complete rework of Annex G and the corresponding program.

The text of this International Standard is based on the following documents:

Draft	Report on voting
112/583/FDIS	112/589/RVD

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

The language used for the development of this International Standard is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/standardsdev/publications.

A list of all parts in the IEC 60216 series, published under the general title *Electrical insulating materials – Thermal endurance properties*, can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

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- withdrawn,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

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ELECTRICAL INSULATING MATERIALS – THERMAL ENDURANCE PROPERTIES –

Part 6: Determination of thermal endurance indices (TI and ~~RTE~~ RTI) of an insulating material using the fixed time frame method

1 Scope

This part of IEC 60216 specifies the experimental and calculation procedures for deriving the thermal endurance characteristics, temperature index (TI) and ~~relative thermal endurance index (RTE)~~ relative temperature index (RTI) of an electrical insulating material (EIM) using the "fixed time frame method (FTFM)".

In this protocol, the ageing takes place for a small number of fixed times, using the appropriate number of ageing temperatures throughout each time, the properties of the specimens being measured at the end of the relevant time interval. This differs from the procedure of IEC 60216-1, where ageing is conducted at a small number of fixed temperatures, property measurement taking place after ageing times dependent on the progress of ageing.

The diagnostic tests employed in the fixed time frame method are restricted to destructive tests. The method has not yet been applied to non-destructive or proof test procedures.

Both the TI and the ~~RTE~~ RTI determined according to the FTFM protocol are derived from experimental data obtained in accordance with the instructions of IEC 60216-1 and IEC 60216-2 as modified in this part of IEC 60216. The calculation procedures and statistical tests are modified from those of IEC 60216-3 and IEC 60216-5.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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 60212, *Standard conditions for use prior to and during the testing of solid electrical insulating materials*

IEC 60216-1:~~2001~~2013, *Electrical insulating materials – Thermal endurance properties – Part 1: Ageing procedures and evaluation of test results*

IEC 60216-2, *Electrical insulating materials – Thermal endurance properties – Part 2: Determination of thermal endurance properties of electrical insulating materials – Choice of test criteria*

IEC 60216-3:~~2002~~2021, *Electrical insulating materials – Thermal endurance properties – Part 3: Instructions for calculating thermal endurance characteristics*

IEC 60216-4-1, *Electrical insulating materials – Thermal endurance properties – Part 4-1: Ageing ovens – Single-chamber ovens*

IEC 60216-4-2, *Electrical insulating materials – Thermal endurance properties – Part 4-2: Ageing ovens – Precision ovens for use up to 300 °C*

IEC 60216-4-3, *Electrical insulating materials – Thermal endurance properties – Part 4-3: Ageing ovens – Multi-chamber ovens*

IEC 60216-5:2022, *Electrical insulating materials – Thermal endurance properties – Part 5: Determination of ~~relative thermal endurance index (RTE)~~ relative temperature index (RTI) of an insulating material*

IEC 60493-1~~:1974~~, *Guide for the statistical analysis of ageing test data – Part 1: Methods based on mean values of normally distributed test results*

3 Terms, definitions, symbols and abbreviated terms

3.1 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at https://www.electropedia.org/
- ISO Online browsing platform: available at https://www.iso.org/obp

3.1.1
electrical insulating material
EIM
material of low electric conductivity, used to separate conducting parts at different electric potentials or to isolate such parts from the surroundings

~~**3.1.2**~~
~~**assessed thermal endurance index**~~
~~**ATE**~~
~~numerical value of the temperature in degrees Celsius, up to which the control material possesses known, satisfactory service performance in the specified application~~

~~NOTE 1 The ATE of a specific material may vary between different applications of the material.~~

~~NOTE 2 ATE is sometimes referred to as "absolute" thermal endurance index.~~

3.1.2
assessed temperature index
ATI
numerical value of the temperature index in degrees Celsius of the reference EIM

Note 1 to entry: The ATI of a specific material may vary between different applications of the material.

3.1.3
ageing temperature
temperature in degrees Celsius at which a group of specimens is thermally aged

3.1.4
end-point temperature
temperature in degrees Celsius at which a specimen is considered to have reached end-point after ageing for a specified time

3.1.5
candidate ~~material~~ EIM
material for which an estimate of the thermal endurance is required to be determined

Note 1 to entry: The determination is made by simultaneous thermal ageing of the material and a ~~control material~~ reference EIM.

3.1.6
central second moment of a data group
sum of the squares of the differences between the data values and the value of the group mean divided by the number of data items in the group

3.1.7
95 % confidence limit
statistical parameter, calculated from test data, which with 95 % confidence constitutes an upper or lower limit for the true value of a quantity estimated by statistical analysis

Note 1 to entry: This implies that there is only 5 % probability that the true value of the quantity estimated is actually larger (or smaller) than the upper (or lower) confidence limit.

Note 2 to entry: In other connections, confidence values other than 95 % may sometimes be used, e.g. in the linearity test for destructive test data.

3.1.8
~~control material~~ reference EIM
material with known ~~assessed~~ thermal endurance ~~index (ATE)~~, preferably derived from service experience, used as a reference for comparative tests with the candidate ~~material~~ EIM

3.1.9
correlation coefficient
number expressing the completeness of the relation between members of two data sets, equal to the covariance divided by the square root of the product of the variances of the sets

Note 1 to entry: The value of its square is between 0 (no correlation) and 1 (complete correlation).

Note 2 to entry: In this standard, the two data sets are the values of the independent variable and the means of the corresponding dependent variable groups.

3.1.10
correlation time ~~(RTE)~~ for RTI
estimated time to end-point of the ~~control material~~ reference EIM at a temperature equal to its ~~ATE~~ ATI in degrees Celsius

Note 1 to entry: In this document, it is expressed by symbol τ_C, see Clause 10.

3.1.11
correlation time for TI
hypothetical time to end-point used to calculate TI

Note 1 to entry: Its usual value is 20 000 h, see Clause D.1.

3.1.12
covariance, <of data sets>
for two sets of data with equal numbers of elements where each element in one set corresponds to one in the other, sum of the products of the deviations of the corresponding members from their set means, divided by the number of degrees of freedom

3.1.13
degrees of freedom
number of data values minus the number of parameter values

3.1.14
destructive test
diagnostic property test, where the test specimen is irreversibly changed by the property measurement, in a way which precludes a repeated measurement on the same specimen

Note 1 to entry: An example of a destructive test is the measurement of electric strength. An example of a non-destructive test is the measurement of ~~tg~~ dissipation factor tan δ.

3.1.15
end-point line
line parallel to the temperature axis intercepting the property axis at the end-point value

3.1.16
halving interval
HIC
numerical value of the temperature interval in Kelvin which expresses the halving of the time to end-point taken at a time equal to TI

3.1.17
regression analysis
process of deducing the best fit line expressing the relation of corresponding members of two data groups by minimizing the sum of squares of deviations of members of one of the groups from the line

3.1.18
regression coefficients
coefficients of the equation of the best fit line derived by regression analysis

~~**3.1.18**~~
~~**relative thermal endurance index**~~
~~**RTE**~~
~~estimate of the thermal endurance of a candidate material, made by thermal ageing simultaneously with the control material, as described in this standard~~

~~NOTE The value of RTE is the value of the temperature in degrees Celsius at which the estimated time to end-point of the candidate material is the same as the estimated time to end-point of the control material at a temperature equal to its ATE.~~

3.1.19
relative temperature index
RTI
determined by test in relation to the thermal performance of a known reference EIM

3.1.20
significance
probability of a value of a statistical function greater than a specified value

Note 1 to entry: The value is equal to (1–p) where p is the cumulative distribution function value. Significance is conventionally printed in upper case (P).

3.1.21
standard deviation
square root of the variance of a data group or sub-group

3.1.22
standard error of an estimate of the true value of a data group property
value of the standard deviation of the hypothetical sampling population of which the group property may be ~~considered to be~~ a member

Note 1 to entry: For an estimate of the group mean, the standard error is equal to the group standard deviation divided by the square root of the number of data items in the group, and indicates the uncertainty in the estimate of the true value of the mean. This standard is concerned only with means and the difference between two means.

3.1.23
temperature index
TI
numerical value of the temperature in degrees Celsius ~~derived from the thermal endurance relationship at a time of 20 000 h (or other specified time)~~ determined by test by itself

Note 1 to entry: This rating is based on 20 000 h life, unless otherwise specified, based on one of the end-of-life criteria listed in IEC 60216-2.

3.1.24
temperature group, <of specimens>
number of specimens being exposed together to thermal ageing at the same temperature in the same oven

Note 1 to entry: Where there is no risk of ambiguity, either temperature groups or test groups may be referred to simply as “groups”.

3.1.25
test group, <of specimens>
number of specimens removed together from a temperature group for destructive testing

Note 1 to entry: Where there is no risk of ambiguity, either temperature groups or test groups may be referred to simply as “groups”.

3.1.26
thermal endurance graph
graph in which the logarithm of the time to reach a specified end-point in a thermal endurance test is plotted against the reciprocal thermodynamic (absolute) test temperature

3.1.27
thermal endurance graph paper
graph paper having a logarithmic time scale as the ordinate and values proportional to the reciprocal of the thermodynamic (absolute) temperature as the abscissa

Note 1 to entry: The ordinate is usually graduated in powers of ten (from 10 h to 100 000 h is often a convenient range). The abscissa is usually graduated in a non-linear (Celsius) temperature scale oriented with temperature increasing from left to right.

3.1.28
time group, <of specimens>
all test groups removed for testing at the same time

3.1.29
variance of a data group
sum of the squares of the deviations of the data from a reference level defined by one or more parameters divided by the number of degrees of freedom

Note 1 to entry: The reference level ~~may~~ can, for example be a mean value (1 parameter) or a line (2 parameters, here intercept on the axis of the independent variable and slope).

3.2 Symbols and abbreviated terms

The following symbols are used in the calculations of Clauses 6, 7, 12 and Annex A, Annex B and Annex C.

Symbol	Description	Clause
a	Regression coefficient: intercept of regression line with x-axis	6.4.4
b	Regression coefficient: slope of regression line relative to y-axis	6.4.4
b_r	Parameter derived from b for calculation of $\hat{Y}_C$	6.5.3
b_p	Regression coefficient for destructive test calculations	6.3.5

Symbol	Description	Clause
c	Parameter in calculation of χ^2	6.5.1
F	F-distributed variance ratio for linearity test	6.3.4, 6.5.2
g, h, i, j	Indexing parameters for regression calculations	6.3, 6.4
HIC	Halving interval	7.1
k	Number of ageing times	6.1.1
N	Total number of x_{ij} values	6.4.3
n_i	Number of x_{ij} values in time group i	6.1.1
P	Significance of the value of a statistical test function	Annex A, Annex B and Annex C
p_e	End-point property value	6.3
p_{gh}	Property value h in temperature group g (time group i implied)	6.3
$\bar{p}_g$	Mean property value in temperature group g (time group i implied)	6.3
q	Base of logarithms in calculation of χ^2	6.5.1
r	Number of temperature groups selected in time group i	6.3.3
r^2	Square of correlation coefficient	6.4.4
s^2	Total (non-regression) variance of x-values	6.5.2
s^2_{1g}	Variance of property values in temperature group g (time group i implied)	6.3.3
s^2_a	Value of s^2 adjusted to allow for acceptable non-linearity	6.5.2
s^2_r	Parameter derived from s^2 for calculation of $\hat{Y}_c$	6.5.3
t	Student's *t*-distributed stochastic variable	6.5.3
TC, TC_a	Lower confidence limit of TI or TI_a (see s^2_a above)	7.1
$t_{p,N}$	Value of t with probability p and N degrees of freedom	6.5.3
x_{ij}	Value of x, index number j, in time group i	6.3.5
$\bar{x}$	General mean of x-values	6.4.3
$\hat{X}$, $\hat{X}_c$	Estimate of x, and its confidence limit	6.5.3
y_i	Value of y for time group i	6.1.1
$\bar{y}$	General mean of y-values	6.4.3
$\hat{Y}$, $\hat{Y}_c$	Estimate of y, and its confidence limit	6.5.3
z_{ij}	Reciprocal kelvin temperature for ϑ_{ij}	6.1.1
$\mu_2(y)$	Central 2nd moment of y values	6.4.3
v	Total number of property values in time group (i implied)	6.3.3
χ^2	χ^2 distributed variable for variance equality (Bartlett's) test	6.5.1
ϑ_{ij}	Ageing temperature for specimen group j in time group i	6.1.1

Symbol	Description	Clause
Θ_0	273,15 K (corresponding to 0 °C)	6.1.1
τ_i	Ageing time for time group i	6.1.1

4 FTFM protocol

4.1 Principles of FTFM protocol

The FTFM (fixed time frame method) protocol is based upon the principle that thermal ageing for determination of thermal endurance characteristics is carried out over a small number of fixed times, with a sufficient range of ageing temperatures at each time to ensure that the property values determined reach the end-point in a satisfactory manner.

In this it differs from the fixed temperature frame procedure of IEC 60216-1, where a small number of ageing temperatures is employed, with ageing being carried out with testing at intervals, until the end-point has been reached.

4.2 Objective of FTFM protocol

~~The objective of~~ The protocol ~~is to~~ shall achieve the following advantages:

The determination of thermal endurance characteristics is completed in a fixed, predetermined time.

This enables much more efficient planning of the determination and will often have substantial commercial advantage. A simple TI determination ~~will~~ can be completed in 5 kh, whereas by the fixed temperature frame procedure, it ~~may~~ can be necessary for ageing to be considerably prolonged past this time to achieve the end-point at the lowest chosen ageing temperature.

Each temperature to end-point (i.e. time-group mean) in the thermal endurance regression is based on the temperatures selected in a time group. The number of temperatures selected may be any number between three and the number of temperature groups in a time group.

Since the largest source of systematic error in the fixed temperature frame procedure is temperature error (actual indication error or temperature distribution error), systematic errors can be considerably reduced. Errors from this source can lead to results which are either inaccurate or invalid through incorrect assessment of linearity.

5 TI determination

5.1 Ageing procedures

Each test procedure shall specify the shape, dimensions and number of the test specimens, the times of exposure, the property to which TI is related, the methods of its determination, the end-point, and the derivation of the thermal endurance characteristics from the experimental data.

The chosen property should, if possible, reflect in a significant fashion a function of the ~~material~~ EIM in practical use. A choice of properties is given in IEC 60216-2.

To provide uniform conditions, the conditioning of specimens after removal from the oven and before measurement ~~may need to~~ should be specified.