

Guide for the determination of thermal endurance properties of electrical insulating materials —

Part 3: Instructions for calculating thermal endurance characteristics —

Section 3.2 Calculations for incomplete data: proof test results up to and including the median time to end-point (equal test groups)

The European Standard EN 60216-3-2:1995 has the status of a
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ICS 29.040.20

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- British Industrial Ceramic Manufacturers' Association
- British Telecommunications plc
- Department of Trade and Industry (National Measurement Accreditation Service)
- EEA (The Association of the Electronics, Telecommunications and Business Equipment Industries)
- Electrical and Electronic Insulation Association (BEAMA Ltd.)
- Electricity Association
- Federation of the Electronics Industry
- Ministry of Defence
- Rotating Electrical Machines Association (BEAMA Ltd.)
- Society of Environmental Engineers
- Transmission and Distribution Association (BEAMA Ltd.)

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- AEA Technology
- Adhesive Tape Manufacturers' Association
- Association of Manufacturers of Domestic Electrical Appliances
- British Cable Makers Confederation
- British Industrial Ceramic Manufacturers' Association
- British Plastics Federation
- Electrical and Electronic Insulation Association (BEAMA Ltd.)
- ERA Technology
- University of Manchester

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National foreword

This British Standard has been prepared by Technical Committee GEL/15 and is the English language version of EN 60216-3-2:1995 *Guide for the determination of thermal endurance properties of electrical insulating materials — Part 3: Instructions for calculating thermal endurance characteristics — Section 2: Calculations for incomplete data: proof test results up to and including the median time to end-point (equal test groups)* published by the European Committee for Electrotechnical Standardization (CENELEC). It is identical with IEC 216-3-2:1993 published by the International Electrotechnical Commission (IEC).

Cross-references

Publication referred to	Corresponding British Standard
	BS 5691 <i>Guide for the determination of thermal endurance properties of electrical insulating materials</i>
HD 611.1 S1:1992 (IEC 216-1:1990)	Part 1:1995 <i>General guidelines for ageing procedures and evaluation of test results</i>
HD 611.2 S1:1992 (IEC 216-2:1990)	Part 2:1995 <i>Choice of test criteria</i>
HD 611.3.1 S1:1992 (IEC 216-3-1:1990)	Part 3 <i>Instructions for calculating thermal endurance characteristics</i> Section 3.1:1995 <i>Calculations using mean values of normally distributed complete data</i>
HD 611.5 S1:1992 (IEC 216-5:1990)	Part 5:1995 <i>Guidelines for the application of thermal endurance characteristics</i>
IEC 493-1:1974	BS 7826 <i>Guide for the statistical analysis of ageing test data</i> Part 1:1995 <i>Methods based on mean values of normally distributed test results</i>

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Summary of pages

This document comprises a front cover, an inside front cover, pages i and ii, the EN title page, pages 2 to 26, an inside back cover and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

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English version

Guide for the determination of thermal endurance
properties of electrical insulating materials
Part 3: Instructions for calculating thermal endurance
characteristics
Section 2: Calculations for incomplete data: proof test
results up to and including the median time to end-point
(equal test groups)

(IEC 216-3-2:1993)

Guide pour la détermination des propriétés
d'endurance thermique de matériaux isolants
électriques
Partie 3: Instructions pour le calcul des
caractéristiques d'endurance thermique
Section 2: Calculs applicables aux résultats
incomplets: résultats des essais d'épreuve de durée
inférieure ou égale au temps médian pour atteindre
le point limite (groupes d'essai égaux)
(CEI 216-3-2:1993)

Leitlinie zur Bestimmung der thermischen
Langzeiteigenschaften von Elektroisierstoffen
Teil 3: Vorschriften zur Berechnung der
thermischen Langzeitkennwerte
Hauptabschnitt 3: Berechnung für unvollständige
Schwellwertprüfergebnisse bis zu und
einschließlich des Median für die Ausfallzeit
(gleiche Prüfgruppen)
(IEC 216-3-2:1993)

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European Committee for Electrotechnical Standardization
Comité Européen de Normalisation Electrotechnique
Europäisches Komitee für Elektrotechnische Normung

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Foreword

The text of the International Standard IEC 216-3-2:1993, prepared by SC 15B, Endurance tests, of IEC TC 15, Insulating materials, was submitted to the formal vote and was approved by CENELEC as EN 60216-3-2 on 1995-03-06 without any modification.

The following dates were fixed:

- latest date by which the EN has to be implemented at national level by publication of an identical national standard or by endorsement (dop) 1996-03-01
- latest date by which the national standards conflicting with the EN have to be withdrawn (dow) 1996-03-01

Annexes designated “normative” are part of the body of the standard.

Annexes designated “informative” are given for information only.

In this standard, Appendix A, Appendix F and Annex ZA are normative and Appendix B, Appendix C, Appendix D and Appendix E are informative.

Annex ZA has been added by CENELEC.

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Introduction

IEC Publication 216: Guide for the determination of thermal endurance properties of electrical insulating materials, is composed of several parts:

- *Part 1: General guidelines for ageing procedures and evaluation of test results; (IEC Publication 216-1)*
- *Part 2: Choice of test criteria; (IEC Publication 216-2)*
- *Part 3: Instructions for calculating thermal endurance characteristics; (IEC Publication 216-3)*
- *Part 4: Ageing ovens; (IEC Publication 216-4)*
- *Part 5: Guidelines for the application of thermal endurance characteristics. (IEC Publication 216-5)*

This part consists of several sections based upon mean values of normally distributed test results. Further sections may be added to take account of other statistical procedures, for example extreme value statistics for those cases where mean value treatments are inadequate. However, there is at present insufficient experience to enable these methods to be used in thermal endurance standards.

This is Section 2. It consists exclusively of calculation instructions. The relevant statistical theory will be found in the appropriate part of IEC Publication 493, or in the references given.

A new Part 3 is in preparation combining and further developing the present Sections 1 and 2 together with the draft of a separate Section: Calculation procedures for normally distributed results from destructive test procedures.

1 Scope and object

This part of IEC Publication 216 gives instructions for calculation of thermal endurance characteristics from data obtained in accordance with IEC Publications 216-1 and 216-2.

Section 1 gives the main sequence calculation scheme for complete normally distributed data, in accordance with the statistical principles set out in IEC Publication 493-1, to which reference should be made for the mathematical background details.

Section 3 gives the calculation sequence for incomplete test results from groups of equal magnitude, where results are available up to and including the median time to end-point.

A worked example, a computer program written in “BASIC” and appropriate statistical tables are given in the appendices.

2 Calculation principles

2.1 Statistical principles

The calculation procedures and instructions given in Clause 3 are based upon the principles and assumptions set out in IEC Publication 493-1. The assumptions made may be expressed in simple form as follows (see IEC publication 493-1, sub-clause 3.7.1):

- 1) The relation between the mean of the logarithms of the times taken to reach a given end-point (“time to end-point”) and the reciprocal thermodynamic (absolute) ageing temperature is linear.
- 2) The values of the deviations of the logarithms of the times to end-point from this linear relation are normally distributed with a variance which is independent of the ageing temperature.

Where the available data are incomplete, in that times to end-point above the median value of each group are not determined, unbiased estimates of the mean and variance of the logarithm of time to end-point within each group, and of the variance of the mean may be determined by a simple algebraic method (see reference in Clause 4).

These estimates are used in a fashion similar to that used for the estimates of mean and variance in Section 1 of this part of Publication 216.

The best estimates of the coefficients of the linear relationship are obtained by the method of least squares, and the confidence limits associated with an estimate using this linear relationship are obtained using the methods of generalized regression analysis.

2.2 Data for analysis

The experimental data are obtained as values of temperature (ϑ °C) and time to end-point (t hours). Each value is transformed to an x or y value:

$x_i = 1/(\vartheta_i + 273)$ value (i) of reciprocal thermodynamic (absolute) temperature.

$y_{ij} = \log(t_{ij})^{1)}$ log of value (j) of time in i'th ageing group (i)

n = number of specimens in each group

k = number of groups (= number of exposure temperatures)

The individual value of t_{ij} is taken as the mid-point of the last proof test cycle before the end point is reached.

Values are included in the calculation up to the m 'th time to end-point, t_{im}

$$m = (n + 1)/2 \quad \text{if } n \text{ is odd}$$

or

$$m = n/2 + 1 \quad \text{if } n \text{ is even}$$

2.3 Restrictions

- The initial numbers of specimens in all groups shall be equal and not less than 11.
- Testing in each group shall be continued until the median time to end-point is reached.
- The cycle time for each group shall be chosen so that the median time to end-point is reached not earlier than the eighth cycle and preferably not later than the twelfth.
- A time to end-point within the first cycle cannot be treated by any known mathematical procedure, and shall be treated as invalid.

Either:

- start again with a new group of specimens;
- adopt the procedure of Appendix F as the mathematical inaccuracy introduced by this procedure will be small.

If the end-point is reached for more than one specimen during the first cycle, it is necessary to discard the group and test a further group, paying particular attention to any critical points of experimental technique.

2.4 Statistical tests

Three tests are included in the calculation procedure.

- Variance equality (Bartlett's χ^2) test.
- Linearity (F) test.
- Dispersion (confidence interval) test.

Test b) and c) may detect deviations from ideal behaviour which are statistically significant but which are too small to have serious practical consequences. Procedures are included to meet these circumstances.

2.4.1 Bartlett's χ^2 test

Inequalities of variance, other than major inequalities, are not considered to lead to serious errors either of temperature index or confidence interval. The value of χ^2 is calculated, and if this value is greater than that corresponding to a significance level of 0,05, the values of χ^2 and its significance level are reported, as in Sub-clause 3.1.5.

2.4.2 F -test for linearity

The F ratio is the ratio of the variance of the deviations of the ageing group means from the regression line [s_2^2 , see equation (11)] to the variance within the ageing groups [s_1^2 , see equation (10)]. A high value of F may result either from a high value of the deviations from the regression line or from a low value of the variance of data within the groups.

¹⁾ In principle, calculations may be made using natural (base e) or Briggsian (base 10) logarithms, as long as the choice is consistent throughout. For this reason, the symbol $\log(y)$ is used throughout, except in Sub-clause 3.1.5.

In order to enable some intermediate results to be comparable with those of the second edition of Publications 216-3:1980 and 216-4:1980, the computer program (Appendix D) uses logarithms to base 10.

The F ratio is tested against tabulated values F_0 at a significance level of 0,05.

In the case of data of very small dispersion, it is possible for a non-linearity to be detected as statistically significant which is of little practical importance.

In order that a result may be obtained even where the F test has failed in this way, a procedure is included as follows.

Increase the value of the variance within the ageing groups (s_1^2) so that the F test gives a result which is just acceptable, that is substitute s_1^2 by an adjusted value $(s_1^2)_a = s_1^2 (F/F_0)$, see Sub-clause 3.1.6 b).

- d) Use this adjusted value to calculate the lower confidence limit of the result, TC_a .
- e) If the lower confidence interval ($TI - TC_a$) is found acceptable ($TI - TC_a \leq 0,6 \text{ HIC}$, see Sub-clause 2.4.3) the non-linearity is deemed to be of no practical importance.

2.4.3 Data dispersion test

When the temperature index, its lower confidence limit and the halving interval (TI , TC and HIC respectively) have been calculated, the lower confidence interval ($TI - TC$) is considered acceptable if:

$$TI - TC \leq 0,6 \text{ HIC}$$

(or $TI - TC_a \leq 0,6 \text{ HIC}$ if appropriate).

In cases where the lower confidence interval exceeds 0,6 HIC by a small margin, still being less than 1,6 HIC, a usable result may yet be obtained (provided $F \leq F_0$) by calculating an adjusted TI_a , that is to say, by subtracting from the calculated TI the amount by which the lower confidence interval exceeds 0,6 HIC,

i.e. if $0,6 \text{ HIC} < TI - TC \leq 1,6 \text{ HIC}$,

and at the same time $F \leq F_0$ report as TI the value

$$TI_a = TI - [(TI - TC) - 0,6 \text{ HIC}] = TC + 0,6 \text{ HIC}$$

instead of the value of TI calculated from the regression equation (see Sub-clause 3.1.8).

If the above conditions are not met, the test result may be reported only in the format $TI_g = \dots$, $HIC_g = \dots$ as in Sub-clause 3.2.3 (see also IEC Publication 216-1, Sub-clause 12.5).

2.5 Internal precision of calculations

Many of the calculation steps involve summing of the differences of numbers or the squares of these differences, where the differences may be small by comparison with the numbers. In these circumstances, it is necessary that the calculations be made with an internal precision of at least six digits and preferably more, to achieve a result precision of three digits. In view of the repetitive and tedious nature of the calculations, it is strongly recommended that they be performed using a programmable calculator or microcomputer, in which case internal precision of 10 or even 12 digits is easily available.

3 Instructions for deriving thermal endurance characteristics

3.1 Numerical derivation and thermal endurance graph

3.1.1 Estimation of group means, variances and variance of means

(These instructions apply to the case of equal groups with times to end-point known up to the median.)

- i) Arrange the logarithms of times to end-point in each group in increasing order

$$y_{i1} \leq y_{i2} \leq \dots \leq y_{im}$$

- ii) Calculate the estimate of mean

$$\bar{y}_i = (1 - \mu)y_{im} + \frac{\mu}{(m-1)} \sum_{j=1}^{m-1} y_{ij} \quad (1)$$

- iii) Calculate the estimate of variance

$$s_{ii}^2 = \alpha \sum_{j=1}^{m-1} (y_{im} - y_{ij})^2 + \beta \left[\sum_{j=1}^{m-1} (y_{im} - y_{ij}) \right]^2 \quad (2)$$

The coefficients μ , α , β (and ε used in equation 11 et seq.) will be found in Appendix F.

3.1.2 General means

Calculate the values of $\bar{x}$, $\bar{y}$ and N . All remaining summations in Clause 3 are with respect to the index i over the range 1 to k .

$$N = mk \quad (3)$$

$$\bar{x} = \Sigma x_i / k \quad (4)$$

$$\bar{y} = \Sigma y_i / k \quad (5)$$

3.1.3 Regression equation and thermal endurance graph

Calculate the coefficients of the regression equation

$$y = a + bx \quad (6)$$

using the equations

$$b = \frac{\Sigma x_i \bar{y}_i - k \bar{x} \bar{y}}{\Sigma x_i^2 - k \bar{x}^2} \quad (7)$$

$$a = \bar{y} - b \bar{x} \quad (8)$$

When the regression line has been established, draw it on the thermal endurance graph, i.e. a graph with $y = \log(t)$ as ordinate, and $x = 1/(\vartheta + 273)$ as abscissa. Usually x is plotted as increasing from the right to the left, and the corresponding values of ϑ in °C are marked on this axis (see Figure 1).

NOTE Special graph paper is obtainable for this purpose.

Alternatively, a computer program executing this calculation may include a sub-routine to plot the graph on the appropriate non-linear scale (see Appendix D, which includes such a sub-routine).

The individual values $y_{ij} = \log(t_{ij})$, and the mean value estimates $\bar{y}_i$ obtained as in Sub-clause 3.1.1, are plotted on the graph at the corresponding values of:

$$x_i = \frac{1}{\vartheta_i + 273} \quad (9)$$

The thermal endurance graph may be completed by drawing the lower 95 % confidence line (see Sub-clause 3.1.7).

3.1.4 Variance calculations

Calculate the pooled value of the variance within the ageing groups

$$s_1^2 = \frac{\Sigma s_{1i}^2}{k} \quad (10)$$

Calculate the variance of the deviations of the ageing group means from the regression line

$$s_2^2 = \frac{1}{\epsilon} \frac{\Sigma (\bar{y}_i - Y_i)^2}{k - 2} \quad (11)$$

where ϵ is found in Appendix E, and

$$Y_i = a + bx_i \quad (12)$$

This may be simplified to

$$s_2^2 = \frac{(\Sigma \bar{y}_i^2 - k \bar{y}^2) - b (\Sigma x_i \bar{y}_i - k \bar{x} \bar{y})}{\epsilon (k - 2)} \quad (13)$$