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TECHNICAL SPECIFICATION

Rotating electrical machines –
Part 18-33: Functional evaluation of insulation systems – Test procedures for form-wound windings – Multifactor evaluation by endurance under simultaneous thermal and electrical stresses

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IEC Central Office
3, rue de Varembé
CH-1211 Geneva 20
Switzerland
Email: inmail@iec.ch
Web: www.iec.ch

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Fax: +41 22 919 03 00

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Technical specifications are subject to review within three years of publication to decide whether they can be transformed into International Standards.

IEC/TS 60034-18-33, which is a technical specification, has been prepared by IEC technical committee 2: Rotating machinery.

This new edition was originally issued as a technical report in 1995 but has been revised extensively prior to re-issue as a technical specification. The main changes with respect to the earlier version of this document are as follows.

a) the requirement to investigate the nature of interactions between thermal and electrical stresses has been abandoned;
b) the use of single stress acceleration factors has been removed;
c) the selection of stress levels has been adjusted and the temperatures are now related to the thermal class temperature of the insulation system;
d) the introduction of end-point criteria;
e) a simplified method to display results.

The text of this technical specification is based on the following documents:

Enquiry draft	Report on voting
2/1581/DTS	2/1601/RVC

Full information on the voting for the approval of this technical specification 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.

A list of all parts of the IEC 60034 series, published under the general title *Rotating electrical machines,* can be found on the IEC website**.**

NOTE A table of cross-references of all IEC TC 2 publications can be found on 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 be

- transformed into an International standard,
- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

A bilingual version of this publication may be issued at a later date.

INTRODUCTION

This document is being issued as a technical specification (according to the ISO/IEC Directives, Part 1, 3.1.1.1) for provisional application in the field of insulation systems for rotating electrical machines, because there is a need for guidance on how standards in this field should be used to meet an identified need.

This document is not to be regarded as an International Standard. It is proposed for provisional application so that information and experience of its use in practice may be gathered. Comments on the content of this document should be sent to the IEC Central Office.

Part 18-1 of IEC 60034 presents general guidelines for the evaluation and classification of insulation systems used in rotating machines.

Part 18-33 deals exclusively with insulation systems for form-wound windings and concentrates on multifactor functional evaluation under simultaneous thermal and electrical ageing.

ROTATING ELECTRICAL MACHINES –

Part 18-33: Functional evaluation of insulation systems – Test procedures for form-wound windings – Multifactor evaluation by endurance under simultaneous thermal and electrical stresses

1 Scope

This part of IEC 60034-18 describes procedures for evaluation of insulation systems by endurance testing where thermal and electrical stresses are applied simultaneously. The procedures are intended for insulation systems used, or proposed to be used, in a.c. electrical machines using form-wound windings. The test procedures provide a comparison of performance between reference and candidate systems at combinations of voltage and temperature which have been used separately to assess quality in the past and which are chosen to produce failures within a suitable timescale and at stresses within practical limits. The outcome of the test on the candidate insulation system will indicate whether it is better or worse than the reference system with proven service experience but will not enable a lifetime in service to be calculated. The evaluation described in this technical specification does not include stress grading.

The test procedures in this technical specification are not intended to establish the interaction between thermal and electrical stress in the ageing process nor endurance lines. If additional information is required on this interaction or in order to achieve endurance lines, it is necessary to undertake further tests in which electrical ageing is carried out at constant temperature and different voltages (IEC 60034-18-32) and thermal ageing is performed at different temperatures and constant voltage.

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 60034-15, *Rotating electrical machines – Part 15: Impulse voltage withstand levels of form-wound stator coils for rotating a.c. machines*

IEC 60034-18-1:2010, *Rotating electrical machines – Part 18-1: Functional evaluation of insulation systems – General guidelines*

IEC/TS 60034-18-42, *Rotating electrical machines – Part 18-42: Qualification and acceptance tests for partial discharge resistant electrical insulation systems (Type II) used in rotating electrical machines fed from voltage converters*

IEC 60085, *Electrical insulation –Thermal evaluation and designation*

IEC 60505, *Evaluation and qualification of electrical insulation systems*

IEC 62539, *Guide for the statistical analysis of electrical insulation breakdown data*

3 General description of test procedures

3.1 Relationship to other standards

The principles of IEC 60034-18-1 and IEC 60505 shall be followed, unless the recommendations or proposals of this part indicate otherwise.

3.2 Test procedures

Testing may be performed either as a full multifactor or as a single point test procedure involving the application of temperature and voltage simultaneously. The single point test procedure provides a comparison at only one combination of thermal and electrical stress. It results in less information on the performance of the candidate system, but this may be sufficient in some cases, such as when there are minor changes in the insulation system (see 5.5). The procedure may also be used as a quality test of an existing or proven insulation system.

3.3 Reference insulation system

A reference insulation system shall be tested using a test procedure equivalent to that used for the candidate system in the same laboratory, using the same test equipment. The performance of the reference insulation system shall be established by service experience under normal operating conditions.

3.4 Characteristics of test procedures

3.4.1 General characteristics

In general, the tests are performed in cycles, each cycle consisting of ageing, conditioning and diagnostic sub-cycles.

3.4.2 Ageing sub-cycle

The ageing sub-cycle includes the simultaneous application of thermal and electrical stresses.

3.4.3 Conditioning and diagnostic sub-cycle

The conditioning sub-cycle involves the application of mechanical stress and moisture. It is followed by voltage tests and other diagnostic tests, as appropriate. When selecting the values of parameters used in this sub-cycle, the set of reference operating conditions (see 3.8) shall be used as guidance. The operations in the sub-cycle are performed in the order listed in Clause 6.

3.5 Means of heating and definition of thermal stress level

3.5.1 Methods of heating

The specimens shall be heated at a rate typical of normal service. Any appropriate means of heating may be used, such as,

a) total enclosure in an oven;

b) heating of the conductors by a high current;

c) the application of heating plates to the mainwall insulation.

Approach (c) is preferred, as it permits better control of the sample temperature within the test length and allows independent cooling of the stress grading region (see 3.6). It is likely that removal of gases (NO_x and O_3) will be required during high voltage ageing.

3.5.2 Thermal stress level

Where practicable, the thermal stress level is defined as the average conductor temperature in the central part of the slot portion. Where it is considered impracticable to make an accurate assessment of this temperature, the temperature of the outer surface of the main insulation in the middle of the slot section may be used if the conductor is not the heat source.

The method used for the measurement of thermal stress level shall be the same for the candidate and the reference systems. Where oven heating is applied, the oven temperature may provide an acceptable value of thermal stress but only when it has been validated by the procedure given in 3.5.3.

Where thermal stress is provided by current heating, the conductor temperature obtained from resistance measurements is an acceptable value of thermal stress if precautions are taken to maintain constant temperature with ± 5 K between specimens and within them.

3.5.3 Temperature measuring techniques

It is recommended that the temperature measurement be made at two stages

a) at equilibrium with only the thermal stress applied;

b) at equilibrium but after the additional application of the electrical stress.

Both temperatures are recorded for information, with the higher temperature defining the thermal stress level.

Measurement of the temperature in the second stage is most safely carried out using the extrapolated cooling curve technique, immediately after the removal of the electrical stress, or by fibre-optic sensors

Higher local temperatures can occur (for example at the stress grading area). These temperatures may be determined by using an IR detector. If failures occur systematically at these points, the ageing stresses may be too high for the stress grading system that has been used. This problem may be solved by an improvement to the stress grading system.

3.6 Means of electrical ageing

It is recommended that power frequency voltage be used to produce electrical ageing. The a.c. ageing voltage is applied between the conductors and the stator core or the outer conductive layer on the surface of the test specimen. The rms value of the test voltage shall be as shown in Table 1. Conventional stress grading materials applied to the surface of the test samples may not be able to provide satisfactory control of the electrical stress at the ends of the test length when subjected to the high voltages and temperatures proposed in Table 1. Overheating and sparking may occur. It may be necessary to apply a special stress grading system to the test coils so that failure only occurs in the mainwall insulation. Examples could be a capacitively coupled stress grading system, an increase in the mainwall thickness and the creation of stress cones. It may be necessary to apply forced air cooling to the stress grading regions. Remedial action may be taken to ensure that adequate electrical stress relief is provided throughout the test.

To reduce the duration of the test, an increased frequency up to 10 times the power frequency may be used. However, care shall be taken that the dielectric losses do not increase the temperature of the insulation so much that the results are affected. The same frequency shall be used for the candidate and reference system.

3.7 Definition of ageing sub-cycle duration

The ageing sub-cycle will be considered to start at the time when the ageing factors are applied and to end when the ageing factors cease to be applied.

3.8 Reference operating conditions

3.8.1 General

Reference operating conditions consist of the most severe levels of all the ageing, conditioning and diagnostic factors for which the insulation system is designed. The reference operating conditions shall be defined.

3.8.2 Reference ageing factors

Thermal and electrical stresses are assumed to be the most significant ageing factors. Their levels are dependent on thermal class and maximum intended rated voltage of the insulation system. See subclause 5.2 for their values.

3.8.3 Reference conditioning factors

The reference conditioning factors may include:

a) maximum mechanical stress, which can act upon that section of winding which the test object simulates, for example stresses due to transient currents at start;

b) maximum expected exposure to moisture in service.

3.8.4 Reference diagnostic factors

The reference diagnostic factors are based on the maximum rated voltage of the insulation system (U_N) and may include the following:

a) mainwall voltage withstand test;

b) interturn voltage withstand test;

c) non-destructive tests, such as, partial discharge and loss tangent.

4 Test objects

4.1 Construction of test objects

4.1.1 General aspects

Test objects shall be constructed to represent adequately the configuration of the finished winding component to be evaluated and shall be subjected to the full normal or intended manufacturing processes as far as possible. If the mechanical attachment of the insulation during service, i.e the way of fixing the coil sides or bars in the slots or endwinding support structure, is considered to influence the ageing processes, it shall be simulated in the test objects.

When using separate coils or bars as models, creepage distances and voltage grading (where required) are to be appropriate to the stresses applied during testing. An electrode shall extend the full slot length of the model and encircle the entire circumference of the coil cross-section. The bar or coil to be tested may be reduced in length.

4.1.2 Considerations on turns and strands in test objects

Where turn insulation is diagnostically tested, it is generally necessary to use complete coils in order to include possible effects of shaping and conductor reinforcement.

Where an interturn impulse voltage diagnostic test is applied, the number of turns in the coil shall be the smallest appropriate for the insulation system, in order to have the highest stress over the interturn insulation.

Where it is required to apply a power-frequency voltage between the turns, the coil is to be wound preferably with two parallel conductors (bifilar) or the coil has to be cut in the endwindings. When using vacuum pressure impregnation (VPI) coils, the cut-through and separation of the conductors in that area shall be made before impregnation.

4.2 Number of test specimens

An adequate number of test specimens shall be aged at each of the combinations of ageing temperatures and voltages that are being used in order to obtain statistical confidence. This number shall not be less than five. The details given in IEC 62539 shall be observed.

NOTE If bars or half-coils are used, the minimum number is five bars or half-coils. If full coils are used, the minimum number is five full coils.

4.3 Initial quality control tests

Each insulating material intended for the preparation of test specimens shall be tested to determine that it meets specifications. The quality tests chosen shall ensure that each material is suitable for the processes required to produce the individual specimens and test object assemblies. Each test specimen shall undergo quality testing before the start of ageing, but the choice of which tests to perform will be left to the discretion of the manufacturer.

4.4 Initial diagnostic tests

Each completed test object shall be subjected to all the conditioning and diagnostic tests selected for the test procedure before starting the first ageing sub-cycle.

5 Ageing sub-cycle

5.1 Ageing stress levels

In the selection of the electrical and thermal stress levels for the ageing sub-cycles, it is important that the mechanism of ageing during these sub-cycles be not significantly different from that in normal service.

5.2 Acceleration factors

The test stresses shall be related to the following reference ageing factor levels:

a) U_N - the maximum rated voltage of the insulation system;

b) T_C - the thermal class temperature as defined in IEC 60085.

Table 1 gives guidelines for the selection of stress levels.

Table 1 – Guidelines for the selection of stress levels

Test level	Electrical stress	Thermal stress
1	1,7 U_N	T_C – 10 K
2	1,9 U_N	T_C
3	2,1 U_N	T_C + 10 K
4	2,3 U_N	T_C + 20 K
5	2,5 U_N	T_C + 30 K

The test levels for converter fed machines depend upon how the rated voltage has been defined. It may be appropriate to increase the test levels by a factor to allow for the maximum overshoot which is likely to arise on the voltage at the machine terminals, as described in

IEC 60034-18-42. This may be as high as 1,7 for a 3 level converter but lower if there are more levels.

In the selection of the ageing temperatures in this table, it has been assumed that the thermal ageing mechanism is the same within the entire test temperature range and that it follows Arrhenius's law with reasonable accuracy. As with single-factor thermal ageing tests, there is the possibility that radical changes in the ageing mechanism will occur at the highest ageing temperatures due, for example, to the proximity of the glass transition temperature or a large change in loss tangent. Such changes of ageing mechanisms can lead to erroneous results and they shall be reported.

It is not essential to combine the electrical and thermal stresses in the way shown in Table 1 if a known or expected interaction between electrical and thermal ageing makes them inappropriate. For example, it may be considered more appropriate to combine electrical stresses 2,3 and 4 with thermal stresses 3,4 and 5 respectively. The important principle is to choose test conditions that produce failures within the required timescale.

5.3 Duration and number of ageing sub-cycles

Each stress combination shall be chosen so that the mean time to failure is not less than 20 days. The lowest stress combination shall produce a mean time to failure greater than 250 days.

The duration of each sub-cycle shall be selected so that about 10 sub-cycles will pass before the mean failure in the group of specimens. Consequently, this duration shall not be less than 2 days nor more than 30 days. It may be appropriate to choose an increasing period for each ageing cycle.

5.4 Full multifactor testing procedure

The ageing factors are applied simultaneously and at least three ageing conditions shall be selected, according to the guidelines in 5.2. The values given in Table 1 are for guidance. If other combinations of test levels are chosen, they shall be justified. For example, a comparison may be preferred with previous combined thermal and electrical testing for which different test levels were used.

5.5 Single-point testing procedure

A single-point test is permitted if there are minor changes in the insulation system. The following procedure may be used.

One appropriate combination of ageing stress levels is selected according to 5.2 and the two ageing stresses are applied simultaneously.

The general principles given in Clause 3 shall be followed. For this procedure, it is essential that the reference system and the candidate system be tested together, using exactly the same test procedure, in the same laboratory, and with the same test equipment.

6 Conditioning and diagnostic sub-cycle

6.1 General

Following each ageing sub-cycle, each specimen is subjected to a series of conditioning and diagnostic tests which may include some or all of the following: mechanical, moisture, voltage, and other diagnostic tests as described in this clause, applied in the order given. The tests that are used shall be reported. If a decision is made to omit either the mechanical or moisture tests, the arguments justifying this shall be reported.

6.2 Mechanical tests

6.2.1 General mechanical test

The applied mechanical stress shall be of the same general nature as would be experienced in service and of a severity comparable with the highest stresses or strains expected in normal service. The procedure for applying this stress can vary with each type of test object, and manner of service. Testing is to be performed at room temperature and without applied voltage.

6.2.2 Shake-table test

The test specimens shall be mounted so that the motion occurs at right angles to the plane of the coils. Testing is to be performed at room temperature and without applied voltage.

The preferred amplitude of the vibration is 0,2 mm or 0,3 mm peak to peak, at a test frequency of 60 Hz or 50 Hz, respectively. This amplitude corresponds to an acceleration of approximately 1,5 *g* (15 m/s^2). If another amplitude or frequency is used, the acceleration shall be the same.

6.3 Moisture tests

6.3.1 General moisture test

Each test object shall be exposed for at least 48 h to an atmosphere producing visible moisture deposition on the winding. The test objects shall be at approximately room temperature, in the 15 °C to 35 °C range. The actual test temperature shall be reported. During this period, voltage is not applied to the test specimens.

Visible and continuous moisture deposition may be achieved by, for example, a fog chamber or condensation chamber.

6.3.2 Moisture test with water immersion

This test may be appropriate for evaluating sealed systems. The complete test object, including the joint connections, is immersed for a period of 30 min in tap water.

At the end of the immersion time, while the test objects are still immersed, a voltage is applied to the test specimens as specified in 6.4. Insulation resistance measurements may be used as an additional test to indicate leakage if so desired.

Following the voltage test, the test objects shall be allowed to dry, preferably overnight, prior to repeating the ageing sub-cycle.

6.4 Voltage tests

In order to check the condition of the test specimens and determine when the end of test life has been reached, a test voltage shall be applied.

The test voltage shall be applied from turn to turn and from coil to frame, in that order.

For a turn to turn test, an appropriate voltage for the winding design and operating conditions shall be selected according to IEC 60034-15.

When a moisture test is used, a power-frequency test voltage is to be applied across the mainwall insulation for 1 min while the test specimens are still wet from exposure, at approximately room temperature. The value of the power frequency test voltage shall be $2 \times U_N$ or 1 000 V, whichever is higher. U_N is defined as the maximum rated voltage of the insulation system under test.

It is important that charging current is not mistaken for electrical breakdown.

For the case of immersed test specimens, a power frequency test voltage of 1,15 × U_N is applied from coil to frame for 1 min. The water shall be at frame potential during the test and at room temperature.

6.5 Other diagnostic tests

When appropriate, other diagnostic tests may be performed.

These diagnostic tests are non-destructive measurements of insulation quality performed at power frequency and shall not be of such a severity as to contribute to the ageing of the insulation system. They may be used to provide end points for the test. Examples are

a) partial discharge inception voltage;

b) maximum discharge magnitude at a selected voltage;

c) loss tangent at U_N;

d) tanδ tip-up value.

7 End point criteria

The end of the test is determined by any of the following;

a) electrical breakdown during the ageing procedure;

b) electrical breakdown after a moisture test;

c) a value of a diagnostic factor in subclause 6.5 which exceeds a pre-agreed level.

When failure occurs during an ageing sub-cycle, the time to failure is the cumulative ageing time under combined thermal and electrical stress. When an end point criterion is reached during a diagnostic test, the time to failure will be the mid-point of the cumulative ageing time between the last two ageing sub-cycles.

8 Analyzing the data, reporting and evaluation

8.1 Analyzing the data

For each of the selected combinations of ageing stresses, the median, log mean, or other characteristic time to failure shall be determined, together with the 90 % confidence limits. The reasons for using the selected method of data reduction shall be reported.

The results may be visualized by a graph showing the logarithm of life versus the number of the test level, e.g. 1, 2, 3 in Table 1, without a regression line.

8.2 Reporting

The paragraphs related to reporting in Clause 5 of IEC 60034-18-1 shall be used as a guide.

8.3 Evaluation

Qualification is determined from the failure data obtained from the candidate and the reference systems at the end of the tests. If the data from the candidate system is no worse than from the reference system, the candidate system is considered to be qualified. That is true if the 90 % confidence interval of the used probability distribution falls above or within that obtained for the reference system.

Bibliography

IEC 60034-18-32, *Rotating electrical machines – Part 18-32: Functional evaluation of insulation systems – Test procedures for form-wound windings – Evaluation of electrical endurance of insulation systems*[1)]

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[1)] Ed.1, to be published (replaces IEC/TS 60034-18-32, *Rotating electrical machines – Part 18: Functional evaluation of insulation systems – Section 32: Test procedures for form-wound windings – Eectrical evaluation of insulation systems used in machines up to and including 50 MVA and 15 kV*)

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

3, rue de Varembé
PO Box 131
CH-1211 Geneva 20
Switzerland

Tel: + 41 22 919 02 11
Fax: + 41 22 919 03 00
info@iec.ch
www.iec.ch