IEEE Std 429-1994
(Revision of IEEE Std 429-1972)

IEEE Recommended Practice for Thermal Evaluation of Sealed Insulation Systems for AC Electric Machinery Employing Form-Wound Preinsulated Stator Coils for Machines Rated 6900 V and Below

Sponsor
**Electric Machinery Committee
of the
IEEE Power Engineering Society**

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Abstract: A test procedure for comparing two or more sealed insulation systems in accordance with their expected life at rated temperature is outlined. The procedure is limited to insulation systems for alternating-current (ac) electrical machines using form-wound preinsulated stator coils rated 6900 V and below.
Keywords: ac electric machinery, insulation system, stator coils, thermal evaluation

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Introduction

(This introduction is not part of IEEE Std 429-1994, IEEE Recommended Practice for Thermal Evaluation of Sealed Insulation Systems for AC Electric Machinery Employing Form-Wound Pre-Insulated Stator Coils for Machines Rated 6900 V and Below.)

The revision of this standard, originally issued in 1972, to an IEEE Recommended Practice brings it up to date with the current IEEE policies and into conformance with the requirements of IEEE Std 99-1980 (Reaff 1992), IEEE Recommended Practice for the Preparation of Test Procedures for the Thermal Evaluation of Insulation Systems for Electric Equipment (which was revised to coordinate with international standards).

This recommended practice is intended to provide an evaluation of the thermal capability of a sealed insulation system. Other aging factors—electrical, mechanical, and environmental—are also known to be important. Test procedures for evaluating those factors, both individually and in combination with each other, will be pursued by other working groups.

Comments on, and suggestions for the improvement of, this standard are welcome, and should be sent to the IEEE Standards Board (see previous page).

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CLAUSE PAGE

IEEE Recommended Practice for Thermal Evaluation of Sealed Insulation Systems for AC Electric Machinery Employing Form-Wound Preinsulated Stator Coils for Machines Rated 6900 V and Below

1. Overview

1.1 Scope

This recommended practice outlines a test procedure for comparing two or more sealed insulation systems in accordance with their expected life at rated temperature. The procedure is limited to insulation systems for ac electrical machines using form-wound preinsulated stator coils rated 6900 V and below.

The intent of this test procedure is to evaluate insulation systems for use with air cooling under severe environmental conditions, where the insulation is exposed to conducting contaminants. This procedure does not cover special requirements, such as those for machines enclosed in gas atmospheres or machines subjected to strong chemicals or submersion in liquid, etc.

The procedure includes instructions for testing candidate systems in comparison with known systems having a proven record of service experience and interpreting the results of these tests.

1.2 Purpose

The purpose of this procedure is to classify sealed insulation systems for the machinery used in severe environmental conditions (and falling within the scope of this recommended practice) in accordance with their temperature capabilities by test, rather than by chemical composition. Data from such tests may be used to establish the temperature classification of new insulation systems before they are service-proven.

In order to provide data from which a base of reference for temperature classification can be established, service-proven sealed systems should also be tested according to this test procedure.

1.3 General conditions

The concepts implemented in this recommended practice are based on IEEE Std 99-1980 .[1]

The intent of this procedure is to classify insulation systems by comparing them to insulation systems in machines with service-proven classifications in the Class A, B, F, or H categories. The temperatures for classification of insulation systems are 105 °C, 130 °C, 155 °C, and 180 °C, respectively.

It is expected that the several insulating materials or components that form any insulation system to, be evaluated by these procedures first will be screened by the appropriate test procedures for each type of material. Thermal indexes for insulating materials can be obtained by following the procedures outlined in IEEE Std 98-1984 .

NOTE — Thermal indexes of insulating materials cannot be used to classify insulation systems. They are to be considered only as screening tests for this system test.

1.4 Methods of evaluation

This test procedure describes models suitable for use in insulation tests. The procedure recommends a series of heat exposures to which the models may be subjected to represent, under accelerated conditions, the cumulative effects of long service. Procedures are given for applying periodic voltage checks, preceded by periods of mechanical stress and moisture, to establish the end point of insulation life by electric failure.

To obtain a good statistical average, for each chosen temperature of heat exposure an adequate number of samples should be carried through the test procedure until failure occurs. It is recommended that the tests on the samples be performed at a minimum of three different test temperatures for each insulation system to be evaluated.

When final results of the tests are reported, and the test life hours are projected to rated temperature, the ratio of "such hours for a new insulation system" to the "test life hours for an old established insulation system" provides a rough measure of the service life expectancy of the new system in relation to that of the old system. Based on the current state of the art in terms of test procedure, no accurate prediction of actual service life can be made from test results alone.

This procedure will permit approximate comparisons only, and cannot be relied upon to completely determine the merits of any particular insulation. Such information can be obtained only from the experience of extended service. By following the general procedures outlined above, the temperature classification in which any new insulation system belongs can be determined.

2. References

This recommended practice shall be used in conjunction with the following publications.

IEEE Std 98-1984 (Reaff 1993), IEEE Standard for the Preparation of Test Procedures for the Thermal Evaluation of Solid Electrical Insulating Materials (ANS[).[2]

IEEE Std 99-1980 (Reaff 1992), IEEE Recommended Practice for the Preparation of Test Procedures for the Thermal Evaluation of Insulation Systems for Electric Equipment (ANSI).

IEEE Std 101-1987 (w1993), IEEE Guide for the Statistical Analysis of Thermal Life Test Data.[3]

[1]information on references can be found in clause 2..
[2]IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA.
[3]IEEE Std 101-1987 has been withdrawn; however, copies can be obtained from the IEEE Standards Department, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA.

IEEE Std 275-1992, IEEE Recommended Practice for Thermal Evaluation of Insulation Systems for Alternating-Current Electric Machinery Employing Form-Wound Preinsulated Stator Coils for Machines Rated 6900 V and Below (ANSI).

3. Test models

3.1 Scope

This clause makes general suggestions concerning appropriate samples of insulating systems that may be subject to the exposures outlined in clause 4. Size and convenience usually require that models, rather than complete machines, be used for evaluation. Suitable models can be designed to adequately represent machines employing form-wound coils in the voltage class 6900 V and below. It is recognized that all machines covered by this range cannot be represented by any single model.

3.2 Models

Models should be made to embody all the essential elements representing a complete winding system and its structural supports. The generic name “formettes” is applied to models coming within the scope of this procedure.

Full and complete design information on the formette should be published at the time the test data is presented. It is recommended that the organization using a formette make available either the formette, the design, or the specialized components so that the results of all functional evaluation tests may be rechecked by independent laboratories.

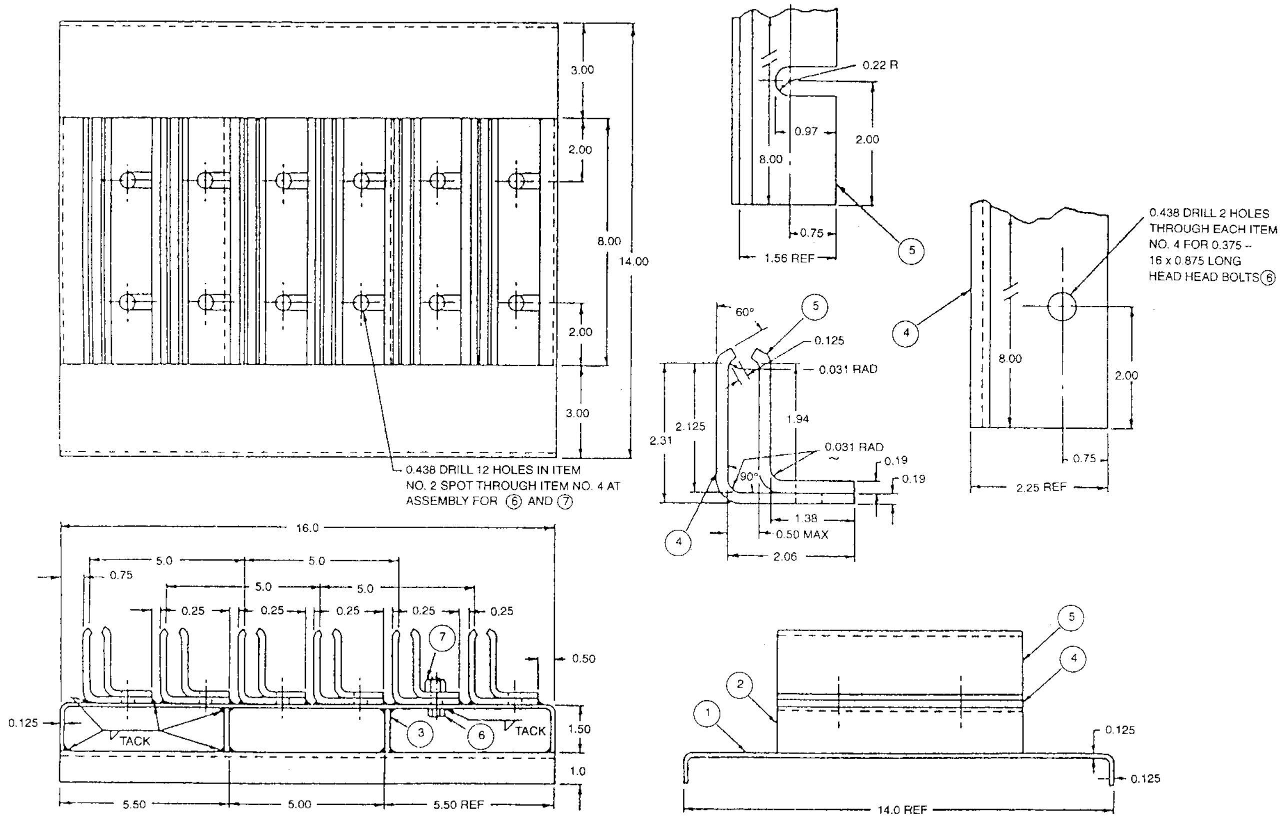
The slot and support structure should simulate the magnetic core and mechanical supports insofar as it is necessary to reproduce operating exposure conditions during the testing. It is recognized that different models may be employed to cover the range of machines included in this test procedure. A typical slot assembly is shown in figure 1.

The test coils and the end-winding bracing structure should contain all the elements employed in the winding they simulate.

Insulation thickness and creepage distances should be appropriate for the voltage class and industry or equipment standards of practices. If the winding turns are not to be tested with impulse testing equipment, the test coils may be wound with two parallel conductors so that turn-to-turn tests can be made with conventional alternating voltage.

Each of the two conductors that comprise the formette coil leads (four joints per coil) should have a joint typical of the series connections used in a full-size machine. The joint should be insulated with the materials used, and by the processes employed, in the actual machine (see figure 2).

Each designer of a specific formette should carefully select the overall design and components with the objective of evaluating the insulation system as a whole. To establish component uniformity and normality, all components used should be subjected to separate screening tests before they are assembled. To establish component adequacy, the completed formettes should be subjected to all of the diagnostic tests described in clause 4. before starting the thermal cycle.



All dimensions in inches.

Inches to millimeters							
0.031	0.787	0.50	12.700	1.56	39.624	3.00	76.200
0.0125	3.175	0.75	19.050	1.94	49.276	5.00	127.000
0.019	4.826	0.875	22.225	2.00	50.800	5.50	139.700
0.22	5.588	0.97	24.638	2.06	52.324	8.00	203.200
0.25	6.350	1.00	25.400	2.125	53.975	14.00	355.600
0.375	9.525	1.38	35.052	2.25	57.150	16.00	406.400
0.438	11.125	1.50	38.100	2.31	58.674		

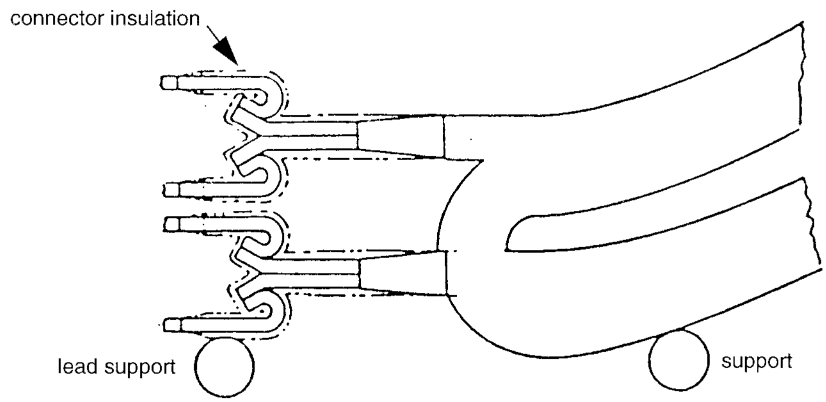
Figure 1—Typical slot assembly

4. Test exposure

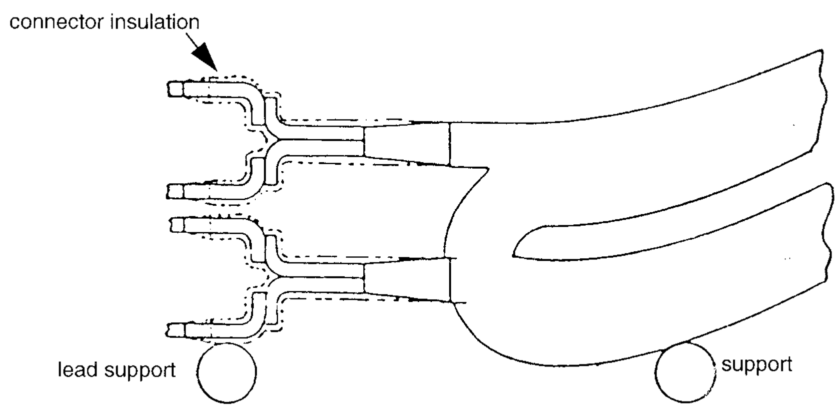
4.1 Scope

To represent, on an accelerated basis, the thermal deterioration effects of service on insulation systems, appropriate heat exposures in repeated cycles are recommended. To check the condition of insulation systems, exposure of the formette to the diagnostic factors of mechanical stress and moisture, followed by voltage after each thermal cycle is recommended. Each model should be tested utilizing repeated cycles of high temperature, mechanical stress, moisture exposure by humidification, and moisture exposure by water immersion, in sequence, until failure occurs as determined by the voltage test.

Before proceeding with the multi-temperature testing, it is suggested that the laboratory or investigator submit a small number (1 or 2) of formettes to extreme aging (for example, ≥ 300 °C for 48 h). To ensure that the procedure at the particular laboratory with the particular formette dimensions is capable of finding thermal degradation, these aged formettes should be subjected to the diagnostic procedure described in this recommended practice.



a) "Stub" connection



b) "U" connection

Figure 2—Typical series joints

Experience has indicated that the best evaluation of a thermally deteriorated, and thus usually brittle, insulation system is obtained by exposure to mechanical stress (which produces cracks in the mechanically stressed parts), then exposure to moisture, and finally application of test voltage.

Despite some obvious disadvantages (noted below), experience has shown that a good oven is a convenient, comparative, and economical device for obtaining high temperatures. This method of aging subjects all parts of the insulation system to the full temperature, while in actual service, a large proportion of the insulation may operate at considerably lower temperatures than the hottest-spot temperature in the oven. Also, the products of decomposition are likely to remain near the insulation during oven aging, whereas they are usually carried away by the ventilating air in actual operation.

4.2 Temperature exposure

The corresponding periods of exposure in each cycle for the different exposure temperatures are listed for the temperature classifications of insulation systems in table 1. To make the best use of facilities, either the time or the temperature may be adjusted. The selected temperature (in °C) of heat exposure for the test should be held constant, within ± 2%.

Table 1—Exposure periods and temperatures for insulation classifications

Exposure temperature* (°C)	Exposure period in days for insulation classifications in °C			
	105 °	130 °	155 °	180 °
250	—	—	—	1
240	—	—	—	2
230	—	—	—	4
220	—	—	1	7
210	—	—	2	14
200	—	1	4	28
190	—	2	7	49
180	1	4	14	—
170	2	7	28	—
160	4	14	49	—
150	7	28	—	—
140	14	49	—	—
130	28	—	—	—
120	49	—	—	—

NOTE — The schedule is selected to fit into a five-day work week, with most of the humidity exposure occurring on weekends. The schedule is arbitrarily based upon an approximate 10° rule, as a guide, for insulation deterioration, which states that the life of the insulation is reduced by one-half for each 10 °C rise in temperature. However, the aging times at the lowest temperature for each of the above four classifications have been shortened purposely in order to allow more tests at the lower temperature.

*The temperature measurements should be taken in the immediate neighborhood of each model, as the temperature is rarely uniform over the entire oven space. Random rearrangement of the specimens from time to time will minimize this effect.

It is recommended that formettes be subjected to the temperature corresponding to the 28 or 49 day exposure period, and to at least two other temperatures in table 1. The other temperatures should be separated by intervals of ≥ 20 °C. When more than three temperatures are studied, intervals of 10 °C may be suitable At each temperature, a statistically adequate number of test coils should be carried through successive cycles of exposure until satisfactory data is obtained.

Normally, it is intended that the temperature exposures be obtained by placing the formettes in enclosed ovens, with just sufficient ventilation or forced convection to maintain uniform temperatures over them. The formettes, at room temperature, should be placed directly in the preheated ovens so as to subject them to a uniform thermal shock in each cycle. Likewise, the hot formettes should be removed from the ovens directly into room air so as to subject them to uniform thermal shock on cooling as well as on heating.

It is recognized that some materials deteriorate more rapidly when the products of decomposition remain in contact with the insulation surface, whereas other materials deteriorate more rapidly when the decomposition products are continuously removed. The same conditions of ventilation and temperature should be maintained for both the test and reference formettes. If the insulation in actual service is arranged so that the products of decomposition remain in contact with it (such as in totally enclosed motors), the test should be designed similarly so that the oven ventilation does not remove these decomposition products.

It is also recognized that, depending on the test facilities available, the type of models employed, and other factors, it may be desirable to modify the methods of exposing and ventilating the coils during these tests. It is also important that, when any two different insulation systems are to be compared, the test formettes of each should be subjected to the same exposure of diagnostic factors.

It is recommended that the periods of exposure time for each of the temperatures and insulation classes be selected so as to result in a mean life of about 10 cycles before failure for each condition (under normal circumstances).

4.3 Mechanical stress exposure

As an initial test before the first cycle of temperature exposure and following each cycle of high temperature exposure as outlined in 4.2, each formette should be subjected to mechanical stress for a period of 1 h.

It is recommended that the mechanical stress applied be of the same general nature as would be experienced in normal service, and of a severity comparable with the highest forces expected in normal service. It is important that whenever any new insulating systems are subjected to stress exposure, the stresses should be applied in the same way as to the reference insulation system so that the test results are comparable.

When a standardized test is to be employed, the preferred method of applying mechanical stress, after each cycle of high temperature exposure, is mounting each formette on a shake table and operating for a period of 1 h with a 60 Hz sinusoidal motion. Peak-to-peak amplitude should be approximately 0.2 mm , corresponding to a peak acceleration of approximately 1.5 times the acceleration of gravity.

The formettes should be mounted so that the motion occurs at a right angle to the plane of the coils so that the coil ends will be free to vibrate as they would under radial end winding forces in an actual machine. This vibration test should be made at room conditions and without applied voltage. After removal from the oven, adequate time should be allowed for the formette to reach room temperature.

4.4 Moisture exposure by humidification

Humidity, in most cases, is recognized as a major cause of variation in the properties of electrical insulation. It can cause several different types of insulation failure under electric stress. The absorption of moisture by solid insulation has the gradual effect of increasing the dielectric loss and reducing the insulation resistance, and also can contribute to a change in electric strength. The presence of condensed moisture on insulation allows overvoltages to seek and discern any cracks and porosities in the insulation.

After each cycle of mechanical stress exposure (as described in 4.3), each formette should be exposed to an atmosphere of 95–100% relative humidity with visible condensation on the winding for a period of 48 h. During this period, voltage should not be applied to the coils.

A time period of 48 h is recommended because experience has shown that a minimum period of this length yields reproducible test results.

NOTE — An atmosphere of 95–100% relative humidity and condensation is readily obtained by covering the floor of the test chamber with a shallow layer of water and heating the water to 5–10 °C above room temperature with an immersion heater. The formette is to remain at a temperature lower than the atmosphere surrounding it in order to ensure continuous condensation. The exterior walls of the moisture chamber should be thermally insulated. The roof of the chamber should not be insulated and should be sloped so as to drain the condensed water to the back or sides of the cabinet and prevent dripping on the samples. The interior of the cabinet should be constructed of corrosion-resistant materials, and junctions of dissimilar metals should be avoided. Doors or removable covers should be constructed with overhanging lips so that moisture collecting around them will drain into the interior of the chamber. Visible and continuous moisture also can be achieved by other means, such as fog chamber, condensation chamber, etc.

4.5 Voltage exposure after humidification

In order to check the condition of the coils and their connections after humidification, and to determine when the end of their useful life has been reached, a voltage of 60 Hz should be applied after the initial exposure to mechanical stress and moisture, and after each successive exposure to heat, mechanical stress, and moisture.

The voltage (as shown in table 2) should be applied in succession to ground, between coils, and between conductors for a period of 10 min following each exposure to moisture while the formettes are still in the humidity chamber, wet from exposure, and at approximately room temperature.

Table 2—Test voltages

Rated line-to-line rms voltage in service (V)	To ground and between coils: alternating rms voltage (V)	Test between conductors*	
		Peak impulse voltage (V)†	Alternating rms voltage (V)
≤ 500	1000	250	115
551–1000	2000	250	115
1001–1500	3000	250	115
1501–2000	4000	250	115
2001–2500	5000	250	115
2501–3500	7000	250	115
3501–4500	9000	250	115
4501–5500	11 000	250	115
5501–6900	13 800	250	115

NOTE — It is recommended that an overcurrent device set at least five times normal charging current be used, or failure is considered if current exceeds 200 mA phase to phase and phase to ground, or 30 mA turn to turn.

*Optional tests depending on available equipment.
†Surge comparison test volts per turn.

Experience has shown that this prolonged time of voltage application in a wet condition is necessary to detect failures. Many of the failures due to this condition occur as the result of creepage along wet surfaces, with a gradual buildup of leakage current that could not occur in the usual 1 min high potential test.

4.6 Moisture exposure by water immersion

Immediately following both the humidification exposure and the subsequent voltage exposure, the complete formette, including the joints of the connections, should be immersed for a period of 30 min in tap water containing a non-ionic wetting agent in a concentration sufficient to reduce the surface tension to a value of ≤ 31 dyn/cm (3.1 μN·m) at 25 °C.

At the end of the immersion time, but while still immersed, a voltage should be applied to the coils as described in 4.7. Following this test, the formette assemblies should be given one or more rinses in normal tap water to remove the wetting agent residue. The formette should then be allowed to air dry, preferably overnight, before continuing the test.

4.7 Voltage exposure during water immersion

At the end of the immersion time, but while still immersed, each formette should be subjected to a 60 Hz high potential test of 1.15 times the rated line-to-line voltage for 1 min, between all conductors and the grounded water.

4.8 Failure criteria

Failure in any of these voltage check tests is indicated by an unusual current. Minor spitting and surface sparking do not constitute a failure, but they should be recorded. In these tests, it is desirable to use an alternating voltage, non-surge, high-potential tester, which trips automatically on overcurrent. (See Note in table 2.) To assure identification of failure, test equipment should be of sufficient capacity (≥ 1 kVA).

Any failure in any component of the insulation system constitutes failure of the entire coil and establishes the end of insulation life.

The end of insulation life is assumed to have occurred at the midpoint of the exposure time between the two consecutive applications of diagnostic factors: The application during which failure was observed. and the last prior application of diagnostic factors with no failure.

5. Procedure for reporting and analyzing

5.1 Data

The total number of hours of heat aging to the end of life (see 4.8) for each coil and for each test temperature should be reported.

5.2 Analysis

For statistical analysis of data, refer to IEEE Std 101-1987 .

5.3 Comparison

If the candidate system (system 2) is to be compared to the reference system (system 1), the regression line of system 1 should be extrapolated to its temperature rating and its mean life value should be determined. The same is done with system 2 for its temperature rating. If the mean life value of system 2 is equal to or greater than that of system 1, then it has at least the thermal reliability at its temperature rating that system 1 had at its temperature rating.

5.4 Extrapolation

It should be understood that extrapolation carries with it a degree of uncertainty. Extrapolation from the lowest test temperature preferably should be a maximum of 20 °C, but it may go up to 30 °C.

5.5 Nonlinear or dissimilar curves

Nonlinear or dissimilar thermal endurance curves may arise when insulation systems are aged over a range of temperatures that cause more than one chemical process during aging. When thermal aging data is plotted on graph paper in the form of log life versus the reciprocal of the absolute temperature, the introduction of new aging mechanisms normally will be shown as a knee, or bend, in the thermal aging curve. Data from the elevated temperature region where the new aging mechanism is activated should not be used to extrapolate to estimated life at service conditions. When this situation occurs additional aging temperature points, beginning at least 10 °C below the lowest existing temperature point, should be obtained and used for extrapolation instead of the points above the bend in the curve.

Dissimilar curves that plot as straight lines may represent greatly different aging rates for the two insulation systems being compared. When this situation occurs, the investigator should obtain additional lower temperature aging points to determine if the endurance curves continue as straight lines, or if a bend occurs below the original aging points.

5.6 System identification

The report should identify the systems being tested, place them in the proper temperature class, and recommend end usage.