IEEE Std 275-1992
(Revision of IEEE Std 275-1981)

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

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Abstract: A test procedure for comparing two or more insulation systems in accordance with their expected life at rated temperature is described. The procedure is limited to insulation systems for ac electric machines using form-wound preinsulated stator coils and rated 6900 V and below. This procedure is intended to evaluate insulation systems for use in usual service conditions with air cooling. It does not cover such special requirements as machines that are enclosed in gas atmospheres, or that are subjected to strong chemicals, to metal dusts, or to submersion in liquids, etc. The procedure includes instructions for testing candidate systems in comparison with known systems having a proven record of service experience and interpretation of the results.
Keywords: electric machinery, ac; form-wound preinsulated stator coils; insulation systems

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Foreword

(This foreword is not a part of 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.)

This recommended practice is a revision of IEEE Std 275-1981. The revision was initiated by the Insulation (now Materials) Subcommittee of the Rotating (now Electric) Machinery Committee of the IEEE Power Engineering Society. At the time this standard was completed, the P275 Working Group had the following membership:

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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

1. Introduction

1.1 Scope

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

It is the intent of this procedure to evaluate insulation systems for use in usual service conditions with air cooling. It does not cover such special requirements as machines that are enclosed in gas atmospheres, or that are subjected to strong chemicals, to metal dusts, or to submersion in liquids, etc.

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

1.2 Purpose

The purpose of this procedure is to classify insulation systems for the machinery within the scope of this standard in accordance with their temperature limits 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.

Service-proven systems shall also be tested according to this test procedure.

1.3 General Conditions

The concepts implemented herein are based on IEEE Std 99-1980 [3].[1]

[1]The numbers in brackets correspond to those of the references listed in Section 2 of this document.

The recognized A, B, F, and H temperature classes, whose IEEE classification temperatures are 105 °C, 130 °C, 155 °C, and 180 °C, respectively, are used in this standard.

It is expected that the several insulating materials, or components, making up any insulation system to be evaluated by these procedures, will first be screened by the appropriate test procedures for each type of material. Thermal indexes for insulating materials may be obtained by following the procedures outlined in IEEE Std 98-1984 [2].

1.4 Methods of Evaluation

This test procedure describes specimens suitable for use in insulation evaluation tests, and recommends a series of exposures to heat to which the specimens may be subjected to represent cumulative effects of long service, under accelerated conditions. 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.

An adequate number of specimens to obtain a good statistical average should be carried through the test procedure until failure occurs, for each chosen temperature of heat exposure. It is recommended that the tests be performed on the indicated number of specimens for at least 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 relation of the service life expectancy of the new system to that of the old system. At the present state of the art, no accurate estimation 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 only be obtained from extended service experience. Following the general procedures outlined above, the temperature classification in which any new insulating system belongs may be determined.

2. References

[1] IEC 34-18-1 (1992), Functional Evaluation of Insulation Systems for Rotating Electrical Machines, Pt. 1: General Guidelines.[2]

[2] IEEE Std 98-1984, IEEE Standard for the Preparation of Test Procedures for the Thermal Evaluation of Solid Electrical Insulating Materials (ANSI).[3]

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

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

[5] IEEE Std 522-1992, IEEE Guide for Testing Turn-to-Turn Insulation on Form-Wound Stator Coils for Alternating-Current Rotating Electric Machines.

[2]IEC publications are available from the Sales Department, Central Office of the International Electrotechnical Commission, 3, rue de Varembé, P.O. Box 131, 1211 Geneva 20, Switzerland.

[3]IEEE publications are available from the Institute of Electrical and Electronics Engineers, Service Center, 445 Hoes Lane, P. O. Box 1331, Piscataway, NJ 08855-1331.

3. Test Models

3.1 Scope

This section makes general suggestions concerning appropriate samples of insulating systems that may be subjected to the exposures outlined in Section 4.

Test specimens may be actual machines, machine components, or models. When it is inconvenient to use actual machines or machine components for the tests because of size, models are used.

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

The models should be made to embody all the essential elements, and should be representative of a complete winding system and its structural supports. The generic name *formettes* shall be applied to models coming within the scope of this procedure.

It shall be the responsibility of the test laboratory to use suitable formettes. Full and complete design information on the formette shall be published at the time of presenting the data. It shall be the responsibility of the organization using a formette to make the formette, the design, or the specialized component available so that the results of all functional evaluation tests may be subject to recheck by independent laboratories.

The slot and support structure shall simulate the magnetic core and mechanical supports insofar as it is necessary to reproduce operational 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 Fig 1.

The test coils and the end-winding bracing structure shall contain all the elements employed in the winding they simulate and shall be considered only as smaller replicas. Insulation thickness and creepages shall be appropriate for the voltage class and industry or equipment standards or 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 may be made with conventional alternating voltage.

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

4. Test Exposures

4.1 Scope

This section specifies appropriate exposures to heat in repeated cycles, which will represent the thermal deteriorating effects of service on insulation systems on an accelerated basis. It will also specify the exposure to diagnostic factors of mechanical stress, moisture, and voltage to apply after each thermal cycle to check the condition of the insulation systems.

Before proceeding with the multi-temperature testing, it is suggested that the laboratory or investigator submit a small number of formettes (one or two) to extreme aging (for example, 300 °C or higher for 48 h). These aged specimens should be subjected to a suitable diagnostic procedure. The procedure chosen will depend upon the operating conditions of the equipment.

In many cases, experience has indicated that the best evaluation of the thermally deteriorated, and thus usually brittle, insulation system is obtained by exposure to mechanical stress, thus producing cracks in the mechanically stressed parts, then exposure to moisture, and finally application of the test voltage.

In other cases, mechanical stress, moisture exposure, and application of voltage might not be the best diagnostic test. It may be appropriate to replace them by selected dielectric tests to check the condition of the insulation.

Experience has shown ovens to be a convenient and economical method of obtaining high temperatures, in spite of some disadvantages, which are listed below. This method of aging subjects all the 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. 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

Table 1 lists the corresponding periods of exposure in each cycle for insulating systems for different temperature classes. Either the time or the temperatures may be adjusted to make the best use of facilities, but comparisons must take such variations into consideration.

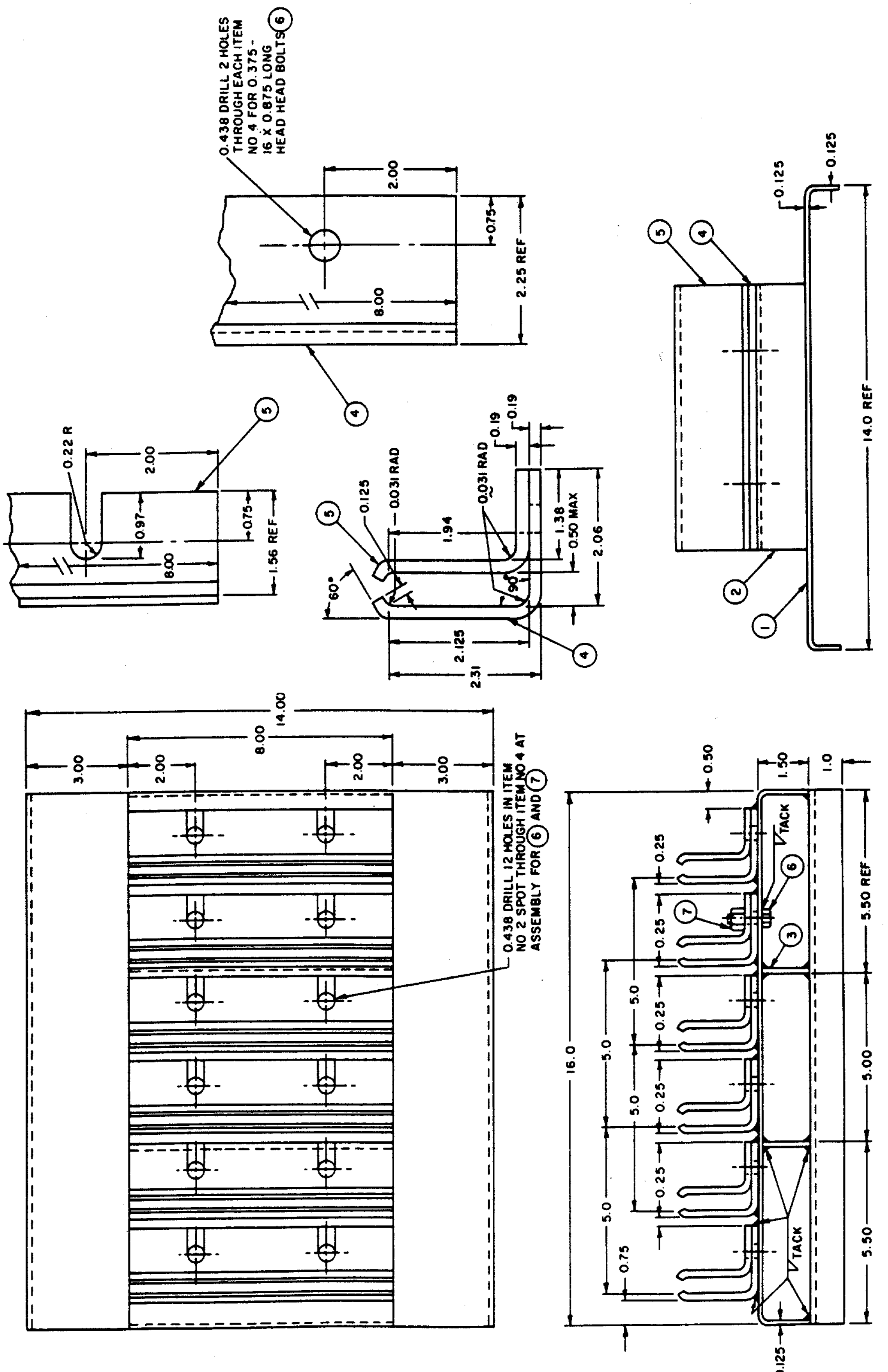

Figure 1—Typical Slot Assembly

The selected temperature of heat exposure for the tests should be held constant within ±2 °C up to 180 °C, ±3 °C above 180 °C.

Table 1—*Temperature and Exposure Periods

	Insulation Classification Temperature (°C)			
Exposure Temperature†	**105 °C**	**130 °C**	**155 °C**	**180 °C**
250				1 day
240				2 days
230				4 days
220			1 day	7 days
210			2 days	14 days
200		1 day	4 days	28 days
190		2 days	7 days	49 days
180	1 day	4 days	14 days	
170	2 days	7 days	28 days	
160	4 days	14 days	49 days	
150	7 days	28 days		
140	14 days	49 days		
130	28 days			
120	49 days			

*The schedule is selected to fit into a five-day work week with most of the humidity exposure occuring on weekends and is based upon an approximate 10°C rule for insulation deterioration, which states that the life of the insulation is reduced one half for each 10°C rise in temperature. However, the aging times at the lowest temperatures for each of the above four classifications have purposely been shortened in order to have 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 rearrangements of the specimens from time to time will minimize this effect.

It is recommended that the specimens 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 high temperatures should be separated by intervals of 20 °C or more. Intervals of 10 °C may be suitable when more than three temperatures are studied. A statistically adequate number of test coils should be carried through successive cycles of exposure at each of the test temperatures until satisfactory data are obtained.

Normally, it is intended that these temperature exposures be obtained by placing the specimens in enclosed ovens, with just sufficient ventilation or forced convection to maintain temperatures uniform over them. The cold specimens should be placed directly in the preheated ovens, so as to subject them to a uniform thermal shock in each cycle. Likewise, the hot specimens 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 continually removed. The same conditions of ventilation and temperature should be maintained for both test and reference coils. If the insulation in actual service is so arranged that the products of decomposition remain in contact with it, as in totally enclosed motors, the tests should then be designed in the same way so that the oven ventilation will 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 coils of each shall be subjected to the *same* exposure of diagnostic factors.

It is recommended that the periods of exposure time for each of the temperatures and each of the insulation classes be selected so as to give 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 specimen shall be subjected to a period of 1 h of mechanical stress.

It is recommended that the mechanical stress applied be of the same general nature as would be experienced in service and of a severity comparable with the highest forces expected in normal service. The procedure for applying this stress may vary with each type of specimen and kind of service. It is important that whenever any new insulating systems are subjected to stress exposure, the stresses should also be applied in the same way to the reference insulation system so that the test results will be comparable.

A method often used of applying mechanical stress to formettes is, after each cycle of high temperature exposure, to mount each formette on a shaker table, and operate it for a period of 1 h with a 60 Hz oscillating motion. Peak-to-peak amplitude should be approximately 0.2 mm, corresponding to a peak acceleration of about 1 1/2 times the acceleration of gravity.

The formettes should be so mounted that the motion occurs at right angles 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 to reach room temperature.

4.4 Moisture Exposure

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

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

Exposure to condensation for a two-day period is recognized to be a more severe test than is usually met in normal service. The time period of two days is recommended because experience has shown that at least this length of time is required for moisture to penetrate throughout the winding, that is, for the insulation resistance to reach a fairly stable value.

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 using an immersion heater to heat the water to 5–10 °C above room temperature. The specimen must 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 of the sides of the cabinet and prevent dripping on the samples. The interior of the cabinet should be constructed of corresion-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 may also be achieved by other means, for example, fog chamber, condensation chamber, etc.

4.5 Voltage Exposure

Each specimen shall be carried through repeated cycles of the high temperature, mechanical stress, and moisture exposure in sequence until failure occurs as determined by the voltage test indicated in Table 2. In order to check the condition of the coils and determine when the end of their useful life has been reached, a 60 Hz voltage will be applied both after the initial exposure to mechanical stress and moisture, and after each successive exposure to heat, mechanical stress, and moisture as follows.

Table 2—Test Voltages

Rated Line-to-Line rms Voltage in Service, Volts	To Ground and Between Coils: † Alternating rms Voltage, Volts	Test Between Conductors*	
		Peak Impulse‡ Voltage, Volts	Alternating rms Voltage, Volts
500 and below	1 000	250	115
551–1000	2 000	250	115
1001–1500	3 000	250	115
1501–2000	4 000	250	115
2001–2500	5 000	250	115
2501–3500	7 000	250	115
3501–4500	9 000	250	115
4501–5500	11 000	250	115
5501–6900	13 800	250	115

*Optional tests depending on a available equipment.
† 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—ø to ø and ø to ground, or 90 mA turn to turn.
‡Surge comparison test volts per turn
Turn-to-turn tests are described in [5].

The voltage will be applied in succession to ground, between coils, and between conductors for a period of 10 min following each exposure to moisture, while the specimens are still in the humidity chamber and are wet from exposure, at approximately room temperature. Experience has shown that this prolonged time of voltage application in the wet condition is necessary to detect failures. Many of the failures in this condition occur as the result of creepage along wet surfaces, with gradual building up of the leakage current, which could not occur in the usual 1 min test.

Failure in any of these voltage check tests will be indicated by an unusual current. Minor spitting and surface sparking should be recorded, but they do not constitute a failure. It is desirable in these tests to use an alternating voltage, *nonsurge*, high-potential tester that automatically trips on overcurrent. (See dagger noted in Table 2.) Test equipment should be of sufficient capacity, 1 kVA or more, to assure identification of failure.

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

It is recognized that by applying the voltages as recommended above, which are fixed by the intended voltages in actual service, markedly different periods of life may be obtained for the same insulating materials, depending on the insulation barriers and lengths of the creepage paths employed.

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 one 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

Report the total number of hours of heat aging to the end of life (see 4.5) for each coil and for each test temperature.

5.2 Analysis

For statistical analysis of data, refer to IEEE Std 101-1987 [4].

5.3 Comparison

When the candidate System 2 is to be compared to the reference System 1, the regression line (log life versus reciprocal of the absolute temperature) of System 1 is extrapolated to its temperature rating, defining a mean test life *X* for the reference system.

In the normal case where the service lives of System 1 and System 2 are required to be the same, the regression line of System 2 is extrapolated to the mean test life *X* of the reference system. If the temperature for System 2 at this test life is equal to or greater than the temperature rating of System 1, then it has, at least, the same temperature rating as System 1.

In special cases, where the required service lives of the two systems are different, the regression line of System 2 is extrapolated to a test life that differs in the same proportion. (For example, if System 2 is required to have twice the service life of System 1, then the extrapolation is carried out to a test life of 2*X*.) In this case, if the temperature for System 2 at this new and different test life is equal to or greater than the temperature rating of System 1, then it has, at least, the same temperature rating as System 1.

5.4 Extrapolation

It must be understood that extrapolation carries with it a degree of uncertainty. Extrapolation from the lowest test temperature should preferably be no greater than 20 °C, but in some cases 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 will normally 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 cannot 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 shall identify the systems being tested, place them in the proper temperature class, and recommend end usage.