Designation: D 2307 – 95

An American National Standard

# Standard Test Method for Thermal Endurance of Film-Insulated Round Magnet Wire[1]

This standard is issued under the fixed designation D 2307; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

## 1. Scope

1.1 This test method covers determination of the thermal endurance of film-insulated round magnet wire in air at atmospheric pressure. It is not applicable to magnet wire with fibrous insulation, such as cotton or glass.

NOTE 1—Other solid conductors such as coated resistance wire may be evaluated by this test method.

1.2 The values stated in inch-pound units are to be regarded as the standard. The SI units in parentheses are provided for information only.

1.3 This test method covers the evaluation of thermal endurance by observing changes in response to ac proof voltage tests. The evaluation of thermal endurance by observing changes in other properties of magnet wire insulation requires the use of different test methods.

1.4 Exposure of some types of film insulated wire to heat in gaseous or liquid environments in the absence of air may give thermal endurance values different from those obtained in air. This fact should be considered when interpreting the results obtained by heating in air with respect to applications where the wire will not be exposed to air in service.

1.5 Electric stress applied for extended periods at a level exceeding or even approaching the discharge inception voltage may change significantly the thermal endurance of film insulated wires, varnished or unvarnished. Under such electric stress conditions, comparisons between materials may also differ from those developed using this method.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

## 2. Referenced Documents

2.1 *ASTM Standards:*

D 115 Test Methods for Varnishes Used for Electrical Insulation[2]

D 5423 Specification for Forced-Convection Laboratory Ovens for Evaluation of Electrical Insulation[3]

2.2 *IEEE Standards:*[4]

IEEE 101 Statistical Analysis of Thermal Life Test Data

## 3. Terminology

3.1 *Definitions:*

3.1.1 *temperature index, n*—a number which permits comparison of the temperature/time characteristics of an electrical insulating material, or a simple combination of materials, based on the temperature in degrees celsius which is obtained by extrapolating the Arrhenius plot of life versus temperature to a specified time, usually 20 000 h.

3.1.2 *thermal endurance, n*—an expression for the stability of an electrical insulating material, or a simple combination of materials, when maintained at elevated temperatures for extended periods of time.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *specimen failure time, n*—the hours at the exposure temperature that have resulted in a specimen failing the proof test (see 9.1).

3.2.2 *time to failure, n*—the hours calculated for a set of specimens, calculated from the individual specimen failure times at an exposure temperature (see 9.2).

## 4. Summary of Test Method

4.1 This test method specifies the preparation of specimens, the aging of these specimens at elevated temperatures, and the periodic testing of the specimens by applying a preselected proof voltage.

4.2 The cyclic exposure to temperature is repeated until a sufficient number of specimens have failed to meet the proof test, and the time to failure is calculated in accordance with Section 9. The test is carried out at three or more temperatures. A regression line is calculated in accordance with Section 10, and the time to failure values plotted on thermal endurance graph paper (see Fig. A1.1) as a function of the exposure temperature.

## 5. Significance and Use

5.1 This test method is useful in determining the thermal endurance characteristics and a temperature index of the film-insulated round magnet wire in air (see 1.4), alone or in

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[1] This test method is under the jurisdiction of ASTM Committee D-9 on Electrical and Electronic Insulating Materials and is the direct responsibility of Subcommittee D09.10 on Magnet Wire Insulation. Originally published as D 2307 – 64T. Last previous edition D 2307 – 78.

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[2] *Annual Book of ASTM Standards*, Vol 10.01.

[3] *Annual Book of ASTM Standards*, Vol 10.02.

[4] Available from the Institute of Electrical and Electronics Engineers, Inc., 345 E. 47th St., New York, NY 10017.

combination with insulating varnish (see Test Methods D 115). This test method may be used as a screening test before making tests of more complex systems or functional evaluation. It may also be used where complete functional systems testing is not feasible.

5.2 Experience has shown that film-insulated wire and electrical insulating varnishes or resins can affect one another during the thermal aging process. Interaction between varnish or resin and film insulation may increase or decrease the relative thermal life of the varnish and film insulated wire combination compared with the life of the film insulated wire tested without varnish. This test method may give indications on the thermal endurance for a combination of insulating varnish or resin and film insulated wire.

5.3 The conductor type or the surface condition of the conductor may also affect the thermal endurance of film-insulated magnet wire. This test method, may be used to determine the thermal endurance characteristics of film insulation on various kinds of conductors. Sizes other than those specified in 7.1.1 may be used but are not recommended for determining thermal endurance characteristics.

5.4 The temperature index determined by this test method is a nominal or relative value expressed in degrees Celsius at 20 000 h. It is to be used for comparison purposes only and is not intended to represent the temperature at which the film insulated wire could be operated.

5.5 There are many factors that may influence the results obtained with this test method. Among the more obvious are the following:

5.5.1 Wire size and film thickness.

5.5.2 Moisture conditions during aging and during voltage tests.

5.5.3 Oven construction:

5.5.3.1 Velocity of air.

5.5.3.2 Amount of replacement air.

5.5.3.3 Elimination of products of decomposition during aging.

5.5.3.4 Oven loading.

5.5.3.5 Accuracy with which the oven maintains temperature.

5.5.4 In most laboratories, aging ovens are limited and, therefore, many different sets of specimens are aged in the same oven. All specimens are not necessarily removed each time the oven is opened. This extra temperature cycling may have a degrading influence.

5.5.5 Care with which specimens are handled, especially during latter cycles when the insulation becomes brittle.

5.5.6 Vibration of specimens. This may have a degrading effect during the later aging cycles.

5.5.7 Electrical characteristics of dielectric test instrument. Refer to 8.4 and 8.5.

5.5.8 Environmental factors such as moisture, chemical contamination, and mechanical stresses, or vibration are factors that may result in failure after the film insulated wire has been weakened by thermal deterioration and are more appropriately evaluated in insulation system tests.

## 6. Apparatus

6.1 *Voltage Source* (see 8.3 and 8.4).

6.2 *Oven* (Specification D 5423).

6.3 *Device for Preparing Twisted Pair Specimens* (See Fig. 1 and Fig. 2).

6.4 *Specimen Holders* (see Fig. 3, Fig. 4, and Fig. 5).

## 7. Test Specimens

7.1 *Preparation*:

7.1.1 Film-insulated magnet wire having noninsulated wire diameters ranging from 0.0113 to 0.1019 in. (0.287 to 2.588 mm) 10 to 29 AWG inclusive can be evaluated as described in this test method.

7.1.2 Form a length of wire approximately 16 in. (400 mm) long into a U shape and twist together for a distance of 4.75 in. (120 mm) with a device as shown in Fig. 1 and Fig. 2. The winding weight applied to the wire specimen while being twisted and the number of twists are given in Table 1.

7.1.3 When a solvent varnish is used, dilute it with a suitable solvent to obtain the required coating thickness.

7.1.4 Use solventless varnishes as received.

7.1.5 Dip the twisted specimens that are to be varnish coated to the depth to cover the wire specimens 0.75 in. (19 mm) beyond the twist area for not less than 30 s, then slowly withdraw at a uniform rate of approximately 4 in./min (100 mm/min). Cure the specimens for the time and at the temperature recommended by the varnish manufacturer. If the application requires it, reverse dip and cure in the opposite direction.

7.2 *Number of Test Specimens*—The accuracy of the test results depends largely upon the number of test specimens aged at each temperature. A greater number of test specimens is required to achieve an acceptable degree of accuracy if there is a wide spread in results among the specimens exposed at each temperature. Use a minimum of 10 specimens for each temperature. More specimens may be aged if desired.

7.3 *Specimen Holder*—It has been found that individual handling of the twisted specimens may introduce premature failures. It is, therefore, mandatory that the specimens be placed in a suitable holder. The recommended holder is shown in Fig. 3 and Fig. 4. Design the holder in a manner that will protect the twisted specimens from external mechanical damage and warpage. Construct the holder so as to allow the ends of the twist to protrude from the holder to make electrical connection for the proof testing as shown in Fig. 5.

7.4 *Electrical Connection Device*—Provide a suitable electrical connection device to make nonmechanical electrical

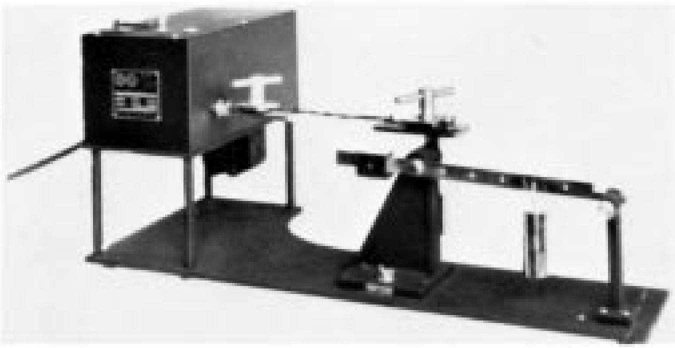


**FIG. 1 Device for Preparing Twisted Pair Specimens, Motorized Unit**

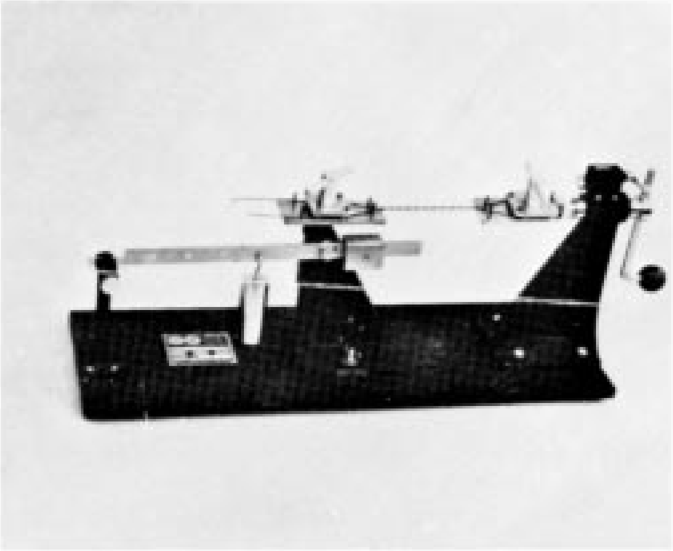


FIG. 2 Device for Preparing Twisted Pair Specimens, Hand-Operated Unit

connection to the test specimens in the holder. The device is connected to a voltage source described in 8.3 and 8.4. A typical device is shown in Fig. 5.

## 8. Procedure

8.1 Prior to the first aging cycle, make sure all specimens pass the proof-voltage test (see Table 2). Age the specimens at elevated temperatures in accordance with Table 3. Remove the specimens from the aging oven and cool to room temperature before testing. Test by applying the voltage specified in Table 2. Take care to prevent damage to the specimens.

8.2 *Exposure Times*—The exposure times given in Table 3 are selected to subject the test specimen to approximately ten cycles before all specimens fail. Table 3 may be extended at the high end of the exposure temperature range to accommodate special high-temperature film insulations. The life of the specimens may be affected by the number of cycles. Log average or median hour values, obtained from test specimens subjected to less than eight cycles or more than twenty cycles at the exposure temperature, may not be reliable. Therefore, the exposure times should be adjusted during the aging to ensure that the number of cycles to failure are within these parameters. For example, if a set of test specimens has been exposed for eight cycles and less than half have failed, the exposure time should be approximately doubled, and if the test shows a 30 % or greater failure rate by the fourth cycle, the exposure time should be reduced by one-half. Expose test specimens to at least three temperatures. Test temperatures should be at least 10°C apart. Select the lowest test temperature to be no more than 20°C above the estimated temperature index of the magnet wire. Space the test temperatures approximately equally so that they cover a range of at least 40°C. The accuracy of the life predicted from the results will increase as the exposure temperature approaches the temperature to which the insulation is exposed in service. The end point at the lowest aging temperature must be at least 5000 h. If the log average or median hours are less than 100, do not use the data. Use aging ovens of the forced-draft design preferably conforming to Specification D 5423.

8.3 *Test Voltages*—The voltages given in Table 2 are selected in order to subject the insulation to a stress of approximately 300 V/mil (12 kV/mm). This value is above the air breakdown value for the space afforded by the insulation films separating the wires. These relatively high values are chosen so that crazing, or other deterioration of the coating is readily detected.

8.4 The voltage to be applied shall be an ac voltage and have a nominal frequency of 50 or 60 Hz of an approximately sine-wave form, the peak factor being within the limits of $\sqrt{2} \pm 5\,\%$ (1.34 to 1.48). The test transformer shall have a rated power of at least 500 V-A and shall provide a current of essentially undistorted waveform under test conditions.

8.5 To detect failure, the fault detection device shall operate when a current of 1.5 to 15 mA flows in the high voltage circuit. The test voltage source shall have a capacity to supply the detection current (1.5 to 15 mA) with a maximum voltage drop of 10 %.

8.6 Apply the proof voltage to the test specimens for approximately 1 s. A relatively short time of application of the test voltage is desirable to minimize the effects of corona and dielectric fatigue.

## 9. Calculation

9.1 *Specimen Failure Time*—The specimen failure time is the sum of the total hours at the time of failure minus one-half the hours of the last cycle. As an example, suppose a given specimen failed to withstand the proof voltage following the ninth 100-h exposure. Thus the total hours would be 900 h minus one-half the hours of the last cycle, 100 h/2 = 50 h, for a failure time of 850 h.

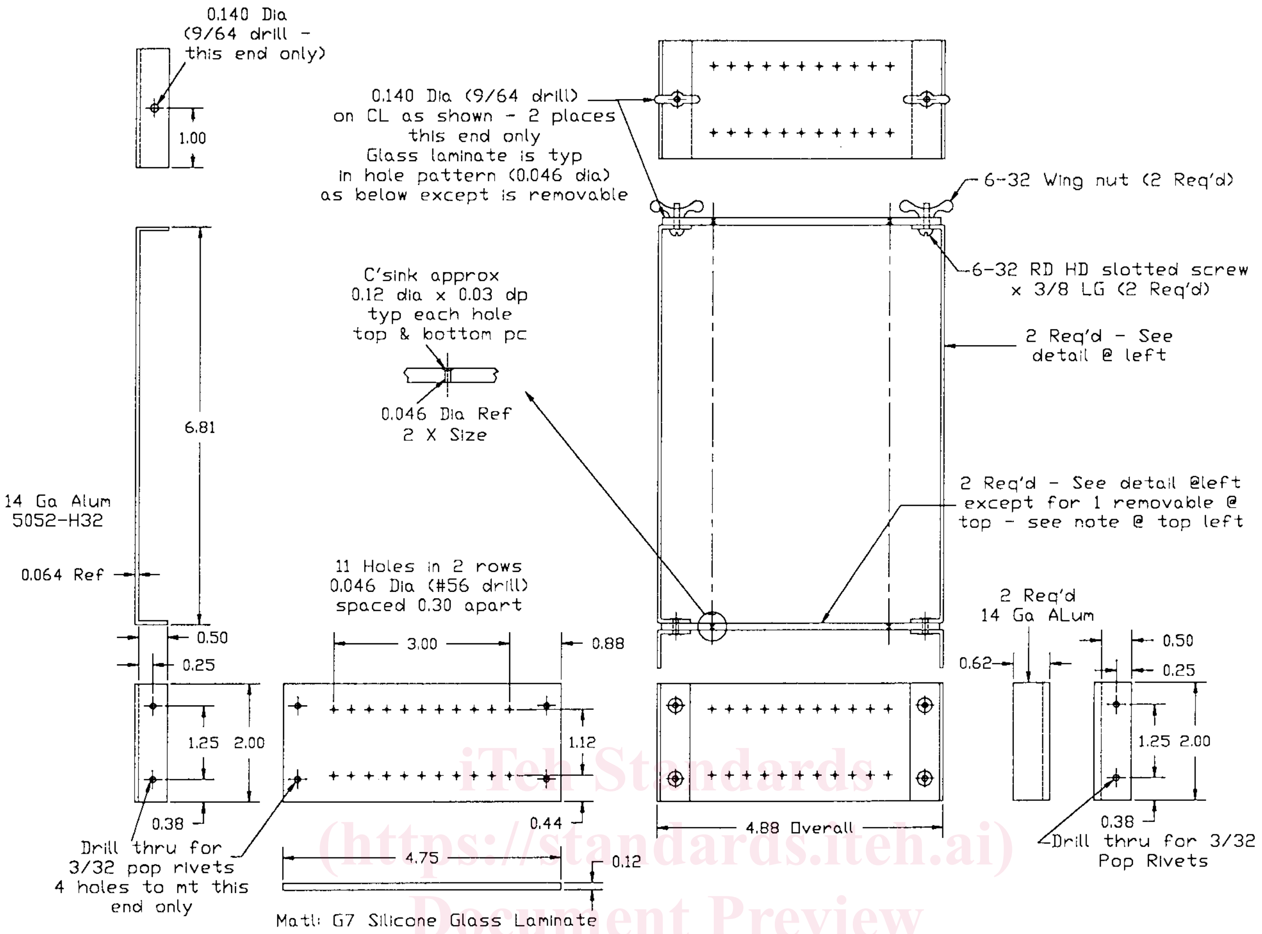
9.2 *Time to Failure*—Calculate the time to failure of a set of specimens at one exposure temperature using either the median or the logarithmic mean. For many materials, the median endurance is statistically valid when specimen failure times are normally distributed. In most cases, the use of the median will significantly reduce testing time, since the test ceases when the median value has been obtained. Exposure times (8.2) are consistent regardless of the method used to obtain the end point.

9.2.1 *Median Calculation Method*:

9.2.1.1 Calculate the time to failure as follows: If the number of specimens at each temperature is $n$, and if $n$ is even, the median endurance of the group of specimens is the average of the failure times of specimens $n/2$ and $(n + 2)/2$. If $n$ is odd, use the specimen failure time of specimen number $(n + 1)/2$.

9.2.1.2 For instance, if $n$ is 10, the logarithm of the failure times of the fifth and sixth specimens must be added and averaged. The time to failure (median log average hours) of the group is the antilogarithm of this average. If $n$ is 11, the failure time of the sixth specimen is equal to the thermal endurance at that temperature.

9.2.2 *Log Average Calculation Method*— When all the specimens have failed, calculate the log average hours at each exposure temperature. Calculate the time to failure (using the logarithmic mean) by dividing the sum of the logarithms of the



Metric Equivalents

| in. | mm | in. | mm | in. | mm |
|---|---|---|---|---|---|
| 0.03 | 0.8 | 0.38 | 9.7 | 1.25 | 31.8 |
| 0.046 | 1.2 | 0.44 | 11.2 | 2.00 | 50.8 |
| 0.064 | 1.6 | 0.50 | 12.7 | 3.00 | 76.2 |
| 0.12 | 3.0 | 0.62 | 15.7 | 4.75 | 120.7 |
| 0.140 | 3.6 | 0.88 | 22.4 | 4.88 | 124.0 |
| 0.250 | 6.4 | 1.00 | 25.4 | 6.81 | 173.0 |
| 0.30 | 7.6 | 1.12 | 28.4 | | |

**FIG. 3 Specimen Holder**

failure times of the individual specimens at each test temperature by the total number of specimens in the group. The time to failure of the group is the antilogarithm of the logarithmic mean (log average hours).

## 10. Calculating and Plotting Thermal Endurance and Temperature Index

10.1 Present the thermal endurance graphically by plotting the time to failure (see Fig. A1.1) versus its respective exposure temperature on graph paper having a logarithmic time scale as the ordinate and the reciprocal of absolute temperature as the abscissa. The temperature indices of 2000 and 20 000 h are derived on the first order of regression calculation presented in the Annex A1: A regression line drawn through these extrapolated points on the graph represents the thermal endurance of the film insulated wire. Industry practice recognizes the point on the thermal endurance graph of the film insulated wire at 20 000 h as the temperature index.

NOTE 2—For a more detailed discussion of the statistical analysis and to determine confidence limits, see the latest issue of IEEE 101. To avoid misleading extrapolations, the correlation coefficient can be calculated as given in Annex A2.

## 11. Report

11.1 Report the following information:

11.1.1 Designation or description of the film insulation, the film build, and the size and type of the conductor metal used (copper, aluminum, etc.).

11.1.2 Designation or description of the insulating varnish when used, including the application method and curing cycle (time and temperature).

11.1.3 Hours to failure of each specimen, at each temperature, including the number of cycles and the exposure time of cycles for each specimen.

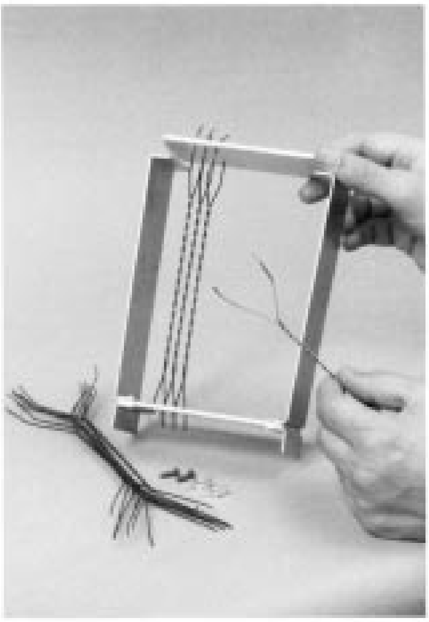


FIG. 4 Specimen Holder

FIG. 5 Specimen Holder and Electrical Connection Device

11.1.4 A graph of the computed regression line through the log average hours or the median hours at each exposure temperature.

11.1.5 A temperature index as determined when the comparative life line is specified. Also, report the comparison life line hours.

## 12. Precision and Bias

12.1 *Precision*—Data from a between-laboratory study[5] involving five laboratories testing MW-15 and MW-24 magnet wires yielded:

| | MW-15 | MW-24 |
|---|---|---|
| Average Temperature Index: | 108.98 | 190.40 |
| Standard Deviation: | 3.37 | 2.07 |

12.2 *Bias*—This test method has no bias because the temperature index is defined in terms of this standard.

## 13. Keywords

13.1 magnet wire; temperature index; thermal endurance

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[5] Supporting data are available in a Research Report from ASTM Headquarters. Request: RR:D9-1030.

**TABLE 1 Tension and Number of Twists for Twisted Pair Construction**

| Nominal Bare Wire Diameter |  | Wire Size AWG ([A]) | Total Twists in 4.75 in. (120 mm) | Winding Weight on Specimens |  |
|---|---|---|---|---|---|
| in. | mm |  |  | kg | lb |
| 0.102 to 0.091 | 2.59 to 2.30 | 10 to 11 | 3 | 10.8 | 24 |
| 0.081 to 0.064 | 2.05 to 1.63 | 12 to 14 | 4 | 5.4 | 12 |
| 0.057 to 0.045 | 1.45 to 1.15 | 15 to 17 | 6 | 2.7 | 6 |
| 0.040 to 0.032 | 1.02 to 0.81 | 18 to 20 | 8 | 1.35 | 3 |
| 0.029 to 0.023 | 0.72 to 0.57 | 21 to 23 | 12 | 0.70 | 1.5[B] |
| 0.020 to 0.016 | 0.51 to 0.40 | 24 to 26 | 16 | 0.34 | ... |
| 0.014 to 0.011 | 0.36 to 0.29 | 27 to 29 | 20 | 0.17 | ... |

[A] Prepare test specimens, of intermediate diameters, in accordance with the requirements for the next smaller AWG size.

[B] For weights less than 1.5 lb, use kilogram weights.

**TABLE 2 Proof-Voltage Test**

NOTE 1—Test voltages are rms values at a nominal frequency of 50 or 60 Hz.

| Difference Between Noninsulated Wire and Insulated Wire Diameters |  | Test Voltage, V |
|---|---|---|
| in. | mm |  |
| 0.0015 to 0.0020 | 0.036 to 0.050 | 500 |
| 0.0021 to 0.0027 | 0.051 to 0.070 | 700 |
| 0.0028 to 0.0035 | 0.071 to 0.090 | 1000 |
| 0.0036 to 0.0051 | 0.091 to 0.130 | 1200 |

**TABLE 3 Recommended Exposure Times in Days Per Cycle[A]**

| Exposure or aging temperature (°C) | Estimated Temperature Index |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|
|  | 105 | 130 | 155 | 180 | 200 | 220 | 240 |
| 320 |  |  |  |  |  |  | 1 |
| 310 |  |  |  |  |  |  | 2 |
| 300 |  |  |  |  |  | 1 | 4 |
| 290 |  |  |  |  |  | 2 | 7 |
| 280 |  |  |  |  | 1 | 4 | 14 |
| 270 |  |  |  |  | 2 | 7 | 28 |
| 260 |  |  |  | 1 | 4 | 14 | 49 |
| 250 |  |  |  | 2 | 7 | 28 |  |
| 240 |  |  |  | 4 | 14 | 49 |  |
| 230 |  |  | 1 | 7 | 28 |  |  |
| 220 |  |  | 2 | 14 | 49 |  |  |
| 210 |  | 1 | 4 | 28 |  |  |  |
| 200 |  | 2 | 7 | 49 |  |  |  |
| 190 | 1 | 4 | 14 |  |  |  |  |
| 180 | 2 | 7 | 28 |  |  |  |  |
| 170 | 4 | 14 | 49 |  |  |  |  |
| 160 | 7 | 28 |  |  |  |  |  |
| 150 | 14 | 49 |  |  |  |  |  |
| 140 | 28 |  |  |  |  |  |  |
| 130 | 49 |  |  |  |  |  |  |
| 120 |  |  |  |  |  |  |  |

[A] A cycle consists of one aging period followed by one proof-voltage test.

## ANNEXES

### (Mandatory Information)

### A1. SIMPLIFIED METHOD FOR CALCULATION OF THE REGRESSION LINE

A1.1 This annex covers a method for quickly plotting the regression line for the endurance data. This method may be used for any number of measurements at various test temperatures. If the information about the confidence limits is required, it is suggested that a more detailed analysis be made in accordance with IEEE 101 Publication.

A1.2 It has been established that many insulations deteriorate in a manner such that the following equation applies:

$$L = Ae^{B/T} \qquad \text{(A1.1)}$$

where:

$L$ = time to failure (log average),