



Standard Test Method for Thermal Endurance of Film-Insulated Round Magnet Wire¹

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 Insulation²

¹ This test method is under the jurisdiction of ASTM Committee ~~D-9~~ D09 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~~. Insulation.

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D 5423 Specification for Forced-Convection Laboratory Ovens for Evaluation of Electrical Insulation³

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 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.

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.

- 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 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.



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

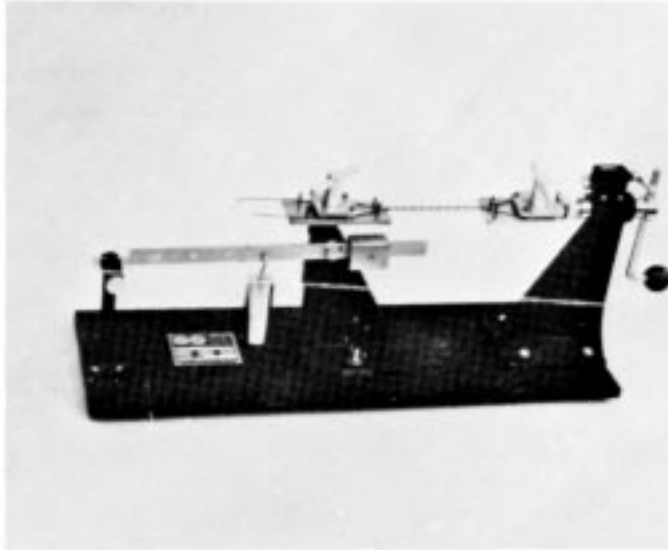


FIG. 2 Device for Preparing Twisted Pair Specimens, Hand-Operated Unit

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.

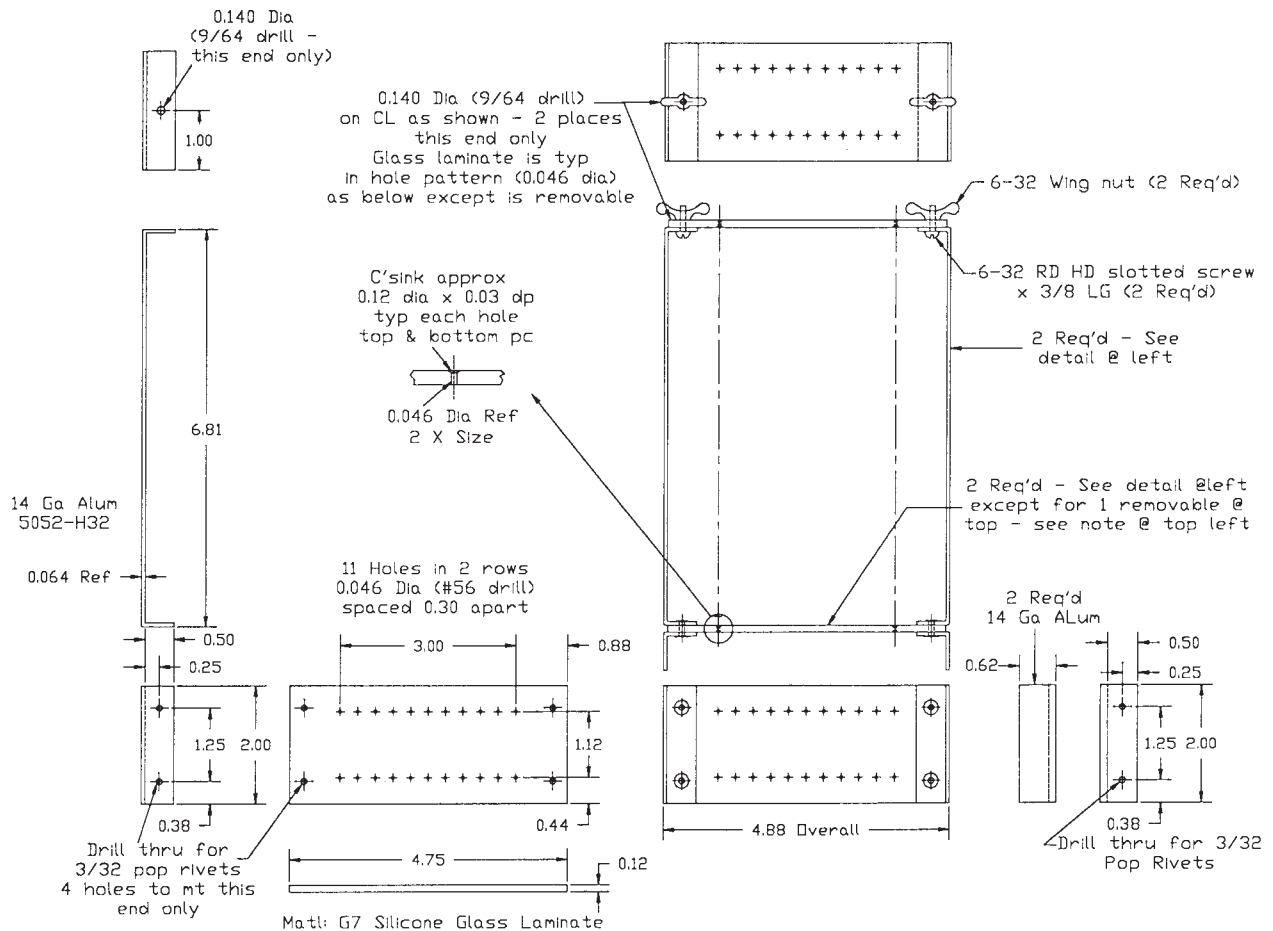
9. Calculation

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, $100 \text{ h}/2 = 50 \text{ h}$, 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 $(n + 1)/2$.



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

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 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.

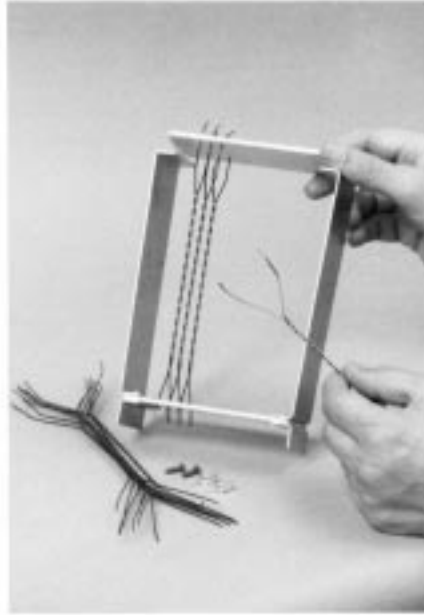


FIG. 4 Specimen Holder

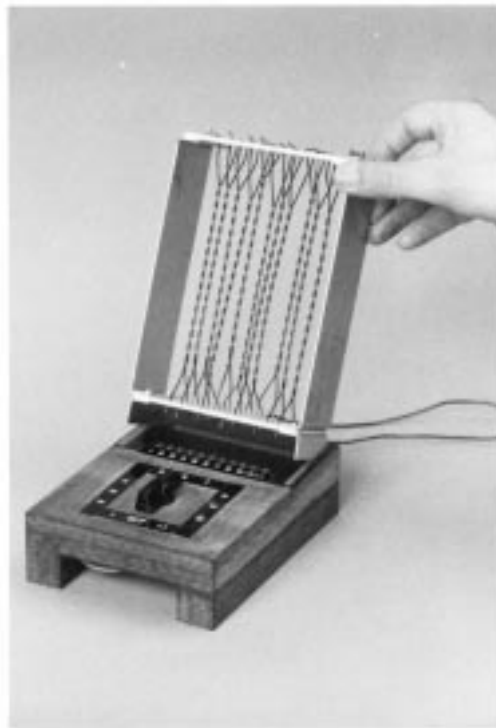


FIG. 5 Specimen Holder and Electrical Connection Device

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.

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 Volt- age, 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.

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 study⁵ involving five laboratories testing MW-15 and MW-24 magnet wires yielded:

Average Temperature Index:	MW-15 108.98	MW-24 190.40
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

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

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:

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

where:

- L = time to failure (log average),
- T = absolute temperature, K,
- A, B = constants for each insulation, and
- e = base of natural logarithms.

(Eq A1.1) may be expressed as a linear function by taking logarithms as follows:

$$\log_{10}L = \log_{10}A + (\log_{10}e) \cdot \frac{B}{T} \quad (\text{A1.2})$$

let:

- $Y = \log_{10}L$
- $a = \log_{10}A$
- $X = 1/T$
- $b = (\log_{10}e) \cdot B$

Then:

$$Y = a + bX \quad (\text{A1.3})$$

A1.3 Thus, data from testing a higher temperature may be plotted on $\log_{10}L$ versus $1/T$ graph paper and a straight line extrapolated to lower temperatures. However, since the nature of logarithmic plots does not allow accurate extrapolation by the method of drawing the best apparent straight line through the data points, a more rigorous method must be used for greater accuracy and uniformity. By the use of the method of least squares, the constants a and b may be derived in terms of the experimental data obtained. These equations are as follows:

$$a = \frac{\Sigma Y - b\Sigma X}{N} \quad (\text{A1.4})$$

$$b = \frac{N \Sigma XY - \Sigma X \Sigma Y}{N \Sigma X^2 - (\Sigma X)^2} \quad (\text{A1.5})$$

where:

- $X = 1/T$ = reciprocal of the test temperature in kelvins ($23^{\circ}\text{C} + 273$),
- N = number of test temperatures used,
- $Y = \log_{10}L$ = logarithms of the specimen failure time (in hours) at each test point,
- Σ = summation of N values,

A1.4 Knowing the constant a and the slope b of the regression line, the temperature at any required life value is calculated as follows:

$$Y = a + bX \quad (\text{A1.6})$$

$$T = \frac{1}{X} = \frac{b}{Y - a} \quad (\text{A1.7})$$

$$\text{Temperature Index at 20 000 h in } ^{\circ}\text{C.} = \frac{b}{4.3010 - a} - 273 \quad (\text{A1.8})$$

$$\text{Temperature Index at 2 000 h in } ^{\circ}\text{C.} = \frac{b}{3.3010 - a} - 273 \quad (\text{A1.9})$$

A1.5 To simplify the handling of the test data used in the (Eq A1.4) to (Eq A1.9), it is suggested that the following steps for a sample calculation be used (see Table A1.1 and Table A1.2):

TABLE A1.1 Commonly Used Test Temperatures in Degrees Celsius and the Corresponding Kelvin Temperature with its Reciprocal and Reciprocal Squared Values (see Table A1.2)

$^{\circ}\text{C}$	K	$X=1/T$	$X^2=1/T^2, K^{-2}$
$^{\circ}\text{C}$	K	$X=1/T, K^{-1}$	$X^2=1/T^2, K^{-2}$
405	378	$2.645\ 50 \times 10^{-3}$	$6.998\ 68 \times 10^{-6}$
105	378	2.646×10^{-3}	6.999×10^{-6}
425	398	$2.512\ 56 \times 10^{-3}$	$6.312\ 97 \times 10^{-6}$
125	398	2.513×10^{-3}	6.313×10^{-6}
430	403	$2.481\ 39 \times 10^{-3}$	$6.157\ 29 \times 10^{-6}$
130	403	2.481×10^{-3}	6.157×10^{-6}
440	413	$2.421\ 31 \times 10^{-3}$	$5.862\ 73 \times 10^{-6}$
140	413	2.421×10^{-3}	5.863×10^{-6}
450	423	$2.364\ 07 \times 10^{-3}$	$5.588\ 81 \times 10^{-6}$
150	423	2.364×10^{-3}	5.589×10^{-6}
465	438	$2.283\ 11 \times 10^{-3}$	$5.212\ 57 \times 10^{-6}$
165	438	2.283×10^{-3}	5.212×10^{-6}
475	448	$2.232\ 14 \times 10^{-3}$	$4.982\ 46 \times 10^{-6}$
175	448	2.232×10^{-3}	4.982×10^{-6}
480	453	$2.207\ 51 \times 10^{-3}$	$4.873\ 08 \times 10^{-6}$
180	453	2.208×10^{-3}	4.873×10^{-6}
485	458	$2.183\ 41 \times 10^{-3}$	$4.767\ 26 \times 10^{-6}$
185	458	2.183×10^{-3}	4.767×10^{-6}
490	463	$2.159\ 83 \times 10^{-3}$	$4.664\ 85 \times 10^{-6}$
190	463	2.160×10^{-3}	4.665×10^{-6}
200	473	$2.114\ 16 \times 10^{-3}$	$4.469\ 69 \times 10^{-6}$
200	473	2.114×10^{-3}	4.470×10^{-6}
210	483	2.070×10^{-3}	4.287×10^{-6}
220	493	$2.028\ 40 \times 10^{-3}$	$4.114\ 40 \times 10^{-6}$
220	493	2.028×10^{-3}	4.114×10^{-6}
225	498	$2.008\ 03 \times 10^{-3}$	$4.032\ 19 \times 10^{-6}$
225	498	2.008×10^{-3}	4.032×10^{-6}
230	503	1.988×10^{-3}	3.952×10^{-6}
240	513	$1.949\ 32 \times 10^{-3}$	$3.799\ 84 \times 10^{-6}$
240	513	1.949×10^{-3}	3.800×10^{-6}
250	523	$1.912\ 05 \times 10^{-3}$	$3.655\ 92 \times 10^{-6}$
250	523	1.912×10^{-3}	3.656×10^{-6}
260	533	$1.876\ 17 \times 10^{-3}$	$3.520\ 02 \times 10^{-6}$
260	533	1.876×10^{-3}	3.520×10^{-6}
270	543	1.842×10^{-3}	3.392×10^{-6}
280	553	$1.808\ 32 \times 10^{-3}$	$3.270\ 01 \times 10^{-6}$
280	553	1.808×10^{-3}	3.270×10^{-6}
300	573	$1.745\ 20 \times 10^{-3}$	$3.045\ 73 \times 10^{-6}$
300	573	1.745×10^{-3}	3.048×10^{-6}
320	593	$1.686\ 34 \times 10^{-3}$	$2.843\ 74 \times 10^{-6}$
320	593	1.686×10^{-3}	2.844×10^{-6}

A1.5.1 Under $^{\circ}\text{C}$ as illustrated in Table A1.2, list each temperature at which a set of specimens was tested.

A1.5.2 In the second and third columns, list the reciprocals ($X = 1/T$) and the reciprocals squared ($X^2 = 1/T^2$) of the above test temperatures converted to degrees kelvins (see also Table A1.1).

A1.5.3 In the fourth column, list the time to failure L in log average hours of each set of specimens and in the fifth column, list the \log_{10} of the value in the fourth column ($Y = \log_{10} L$).

A1.5.4 In the sixth column list the products of X and Y .

A1.5.5 In the seventh column list Y^2 .

A1.5.6 Provide summation for columns 2, 3, 5, 6, and 7, and enter the summation (indicated by Σ) at the bottom of the respective column.

A1.5.7 At the bottom of column 5, below the sum, enter the value of the average of Y , and at the bottom of column 7 enter the value of the average of Y^2 .

A1.5.8 Indicate the number N (number of test temperatures used) on the worksheet.

A1.5.9 Using the values obtained in A1.5.6 and A1.5.8, compute b (Eq A1.5) and a (Eq A1.4) in that order. The constant a will always be negative.

A1.5.10 Using constants a and b , solve for temperature indices in degrees Celsius at 20 000 h (Eq A1.8) and at 2000 h (Eq A1.9).

A1.5.11 Plot the above two temperature points from A1.5.10 on $\log_{10} L$ versus $1/T$ graph paper (Fig. A1.1) and draw the regression line through them.

A1.5.12 Plot the times to failure L at their respective temperatures on the same graph.

TABLE A1.2 Sample Calculations

Temperature (°C)	$X = 1/T$	$X^2 = 1/T^2$	L (h)	$Y = \log_{10} L$	$XY = Y = (\log_{10} L)/T$	Y^2
170	2.25734×10^{-3}	5.09558×10^{-6}	5600	-3.74819	-8.46094×10^{-3}	14.04892
170	2.257×10^{-3}	5.096×10^{-6}	5600	3.748	8.461×10^{-3}	14.049
185	2.18341×10^{-3}	4.76728×10^{-6}	2600	-3.41497	-7.45628×10^{-3}	11.66204
185	2.183×10^{-3}	4.767×10^{-6}	2600	3.415	7.456×10^{-3}	11.662
200	2.11416×10^{-3}	4.46967×10^{-6}	1500	-3.17609	-6.71476×10^{-3}	10.08755
200	2.114×10^{-3}	4.470×10^{-6}	1500	3.176	6.715×10^{-3}	10.088
215	2.04918×10^{-3}	4.19914×10^{-6}	640	-2.80618	-5.75037×10^{-3}	7.87465
215	2.049×10^{-3}	4.199×10^{-6}	640	2.806	5.750×10^{-3}	7.875
Σ	8.60409×10^{-3}	18.53167×10^{-6}		13.14543	28.38235×10^{-3}	43.67375
Σ	8.604×10^{-3}	18.532×10^{-6}		13.145	28.382×10^{-3}	43.67375

$$N = 4 \text{ Avg } Y = 3.286358$$

Avg $Y^2 = 10.8$

and $(\text{Avg } Y)^2 =$

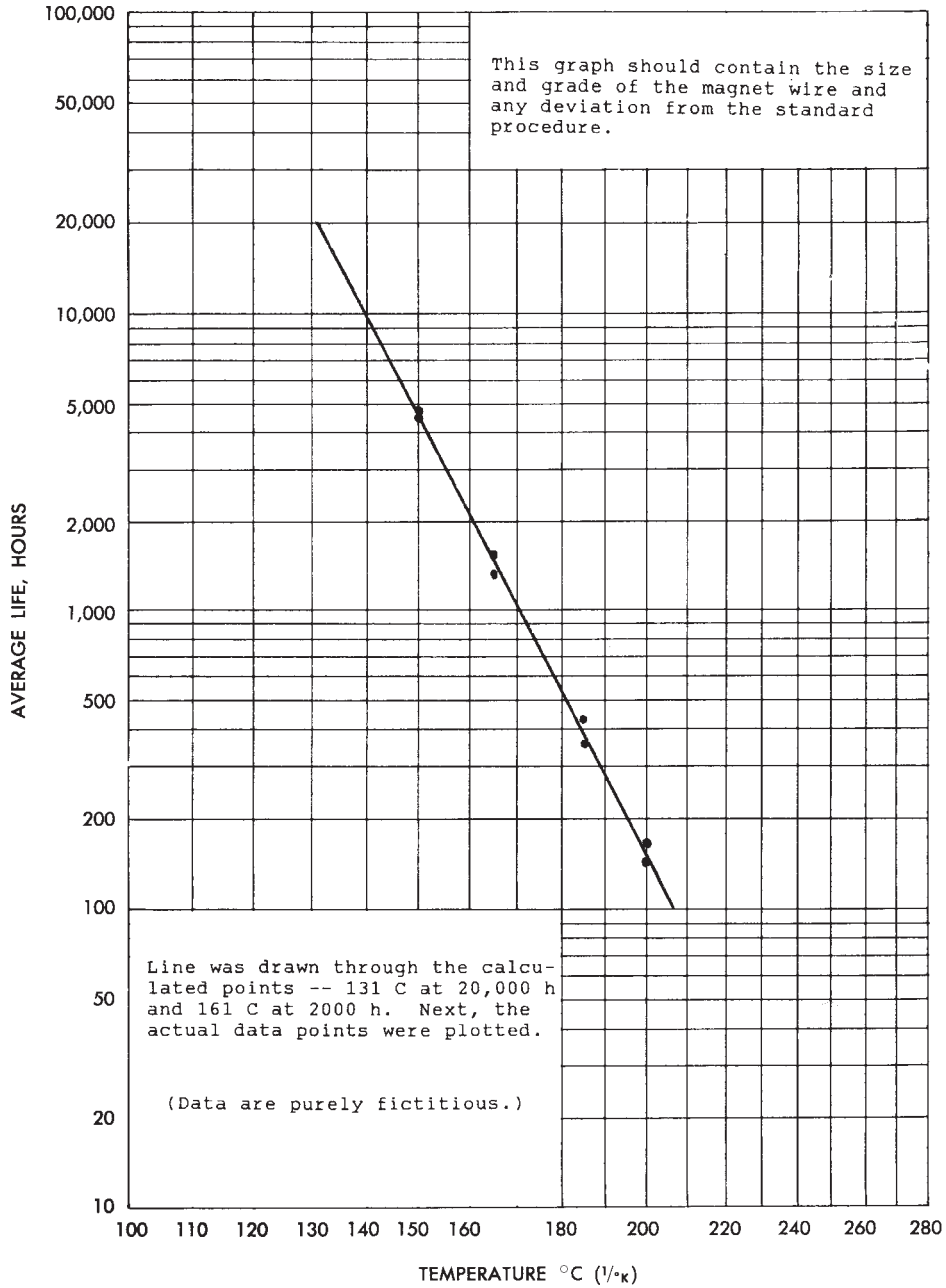
For this example $N = 4$ Therefore: Avg $Y = 3.286358$

$$b = \frac{N \Sigma XY - \Sigma X \Sigma Y}{N \Sigma X^2 - (\Sigma X)^2} = \frac{4 \times 28.38235 \times 10^{-3} - 18.5316704 \times 10^{-6} \times 13.14543}{4 \times 18.532 \times 10^{-6} - 8.60409 \times 10^{-3} \times 8.60409 \times 10^{-3}} = 4 \text{ 411.94}$$

$$a = \frac{\Sigma Y - b \Sigma X}{N} = \frac{13.14533 - 4 \times 411.943 \times 8.60409 \times 10^{-3}}{4} = -6.20382$$

$$\text{Temperature Index at } 20\text{-}000 \text{ hrs in } ^\circ\text{C} = \frac{b}{Y - a} - 273 = \frac{4 - 411.943}{3.3010 + 6.20382} - 273 = 147^\circ\text{C}$$

$$\text{Temperature Index at } 2\text{-}000 \text{ hrs in } ^\circ\text{C} = \frac{b}{Y - a} - 273 = \frac{4 - 411.943}{3.3010 + 6.20382} - 273 = 191^\circ\text{C}$$



NOTE 1—This graph should contain all appropriate information regarding the insulating materials.

FIG. A1.1 Plot of Regression Line Based on Sample Calculation (Table A1.1)

A2. CORRELATION COEFFICIENT

A2.1 The correlation coefficient r is a measure of the amount of relationship between variables. When $r = 1.0$, a perfect association between the variable exists, and when $r = 0$, a completely random relation exists.

$$r = \frac{a\sum Y + b\sum XY - N\bar{Y}^2}{\sqrt{\sum Y^2 - n\bar{Y}^2}} \tag{A2.1}$$

$$r = \frac{a\sum Y + b\sum XY - N(\text{Avg } Y)^2}{\sqrt{\sum Y^2 - N(\text{Avg } Y)^2}} \tag{A2.1}$$

where:

N = number of test temperatures used,
 X, Y = the variables (see Annex A1).

A2.2 *Linearity of Data:*

A2.2.1 If the correlation coefficient r is equal to or greater than 0.95, the data is said to be linear and the data points will be reasonably close to a straight line. In the event that the correlation coefficient is less than 0.95, the data is said to be nonlinear and an additional test should be made at a temperature below the lowest previous temperature.

A2.2.2 The new temperature point may be 10°C below the previous lowest temperature point. When recalculating the temperature index and correlation coefficient, one temperature point may be deleted, starting with the highest temperature, for each new temperature point obtained.

A2.2.3 The data will be linear if the thermal deterioration of the film insulated wire or the varnished film insulated wire appears as one chemical reaction. Nonlinearity may indicate the following:

A2.2.3.1 Two or more reactions that have different activation energies (slopes) are predominant at different temperatures within the testing range; or

A2.2.3.2 Errors have been introduced through the sampling technique or the testing procedure, or both.

A2.2.4 It should be noted that nonlinear results may provide useful engineering data when plotted on the thermal endurance graph even when the data cannot be extrapolated appropriately to give a temperature index (TI). If at least three data points are available or can be obtained for the thermal endurance graph at the lower end of the temperature scale that are acceptably linear, they can be used to plot a regression line. In this case a TI can be obtained by extrapolation, but the fact that data at higher temperature(s) has been discarded should be reported in such cases.

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