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

This standard is issued under the fixed designation D2307; 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.

1.2 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.

1.3 It is possible that exposure of some types of film insulated wire to heat in gaseous or liquid environments in the absence of air will give thermal endurance values different from those obtained in air. Consider this possibility when interpreting the results obtained by heating in air with respect to applications where the wire will not be exposed to air in service.

1.4 It is possible that electric stress applied for extended periods at a level exceeding or even approaching the discharge inception voltage will change significantly the thermal endurance of film insulated wires. Under such electric stress conditions, it is possible that comparisons between materials will also differ from those developed using this method.

1.5 This test method is similar to IEC 60172. Differences exist regarding specimen preparation.

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

1.7 *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 establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D1676 Test Methods for Film-Insulated Magnet Wire

D1711 Terminology Relating to Electrical Insulation

D3251 Test Method for Thermal Endurance Characteristics of Electrical Insulating Varnishes Applied Over Film-Insulated Magnet Wire

D5423 Specification for Forced-Convection Laboratory Ovens for Evaluation of Electrical Insulation

2.2 *Other Standards:*

IEC 60172 Statistical Analysis of Thermal Life Test Data[3]

IEEE 101 Statistical Analysis of Thermal Life Test Data[4]

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 *thermal endurance cycle, n*—one oven exposure period followed by a proof voltage test.

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

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[1] This test method is under the jurisdiction of ASTM Committee D09 on Electrical and Electronic Insulating Materials and is the direct responsibility of Subcommittee D09.17 on Thermal Characteristics.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Available from International Electrotechnical Commission (IEC), 3 rue de Varembé, Case postale 131, CH-1211, Geneva 20, Switzerland, http://www.iec.ch.

[4] Available from Institute of Electrical and Electronics Engineers, Inc. (IEEE), 445 Hoes Ln., P.O. Box 1331, Piscataway, NJ 08854-1331, http://www.ieee.org.

***A Summary of Changes section appears at the end of this standard**

3.3 For definitions of terms related to electrical insulation, see Terminology D1711.

4. Summary of Test Method

4.1 This test method specifies the preparation of specimens, the exposure 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. 6) 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 thermal indices of film-insulated round magnet wire in air (see 1.3) (see Test Method D3251). This test method is used as a screening test before making tests of more complex systems or functional evaluation. It is also 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 exposure process. Test Method D3251 provides indications on the thermal endurance for a combination of insulating varnish or resin and film insulated wire. It is possible that interaction between varnish or resin and film insulation will 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.

5.3 The conductor type or the surface condition of the conductor will affect the thermal endurance of film-insulated magnet wire. This test method is used to determine the thermal endurance characteristics of film insulation on various kinds of conductors. The use of sizes other than those specified in 7.1.1 is permissible but is not recommended for determining thermal endurance characteristics.

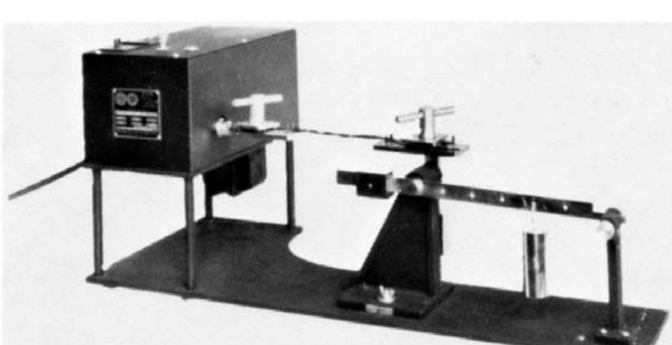


FIG. 1 Device for Preparing Twisted Pair Specimens, Motorized Unit

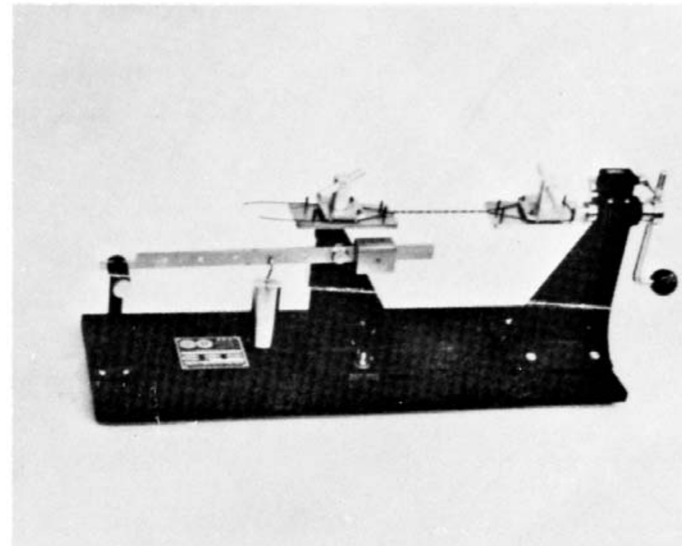


FIG. 2 Device for Preparing Twisted Pair Specimens, Hand-Operated Unit

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 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 proof 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 thermal exposure.

5.5.3.4 Oven loading.

5.5.3.5 Accuracy with which the oven maintains temperature.

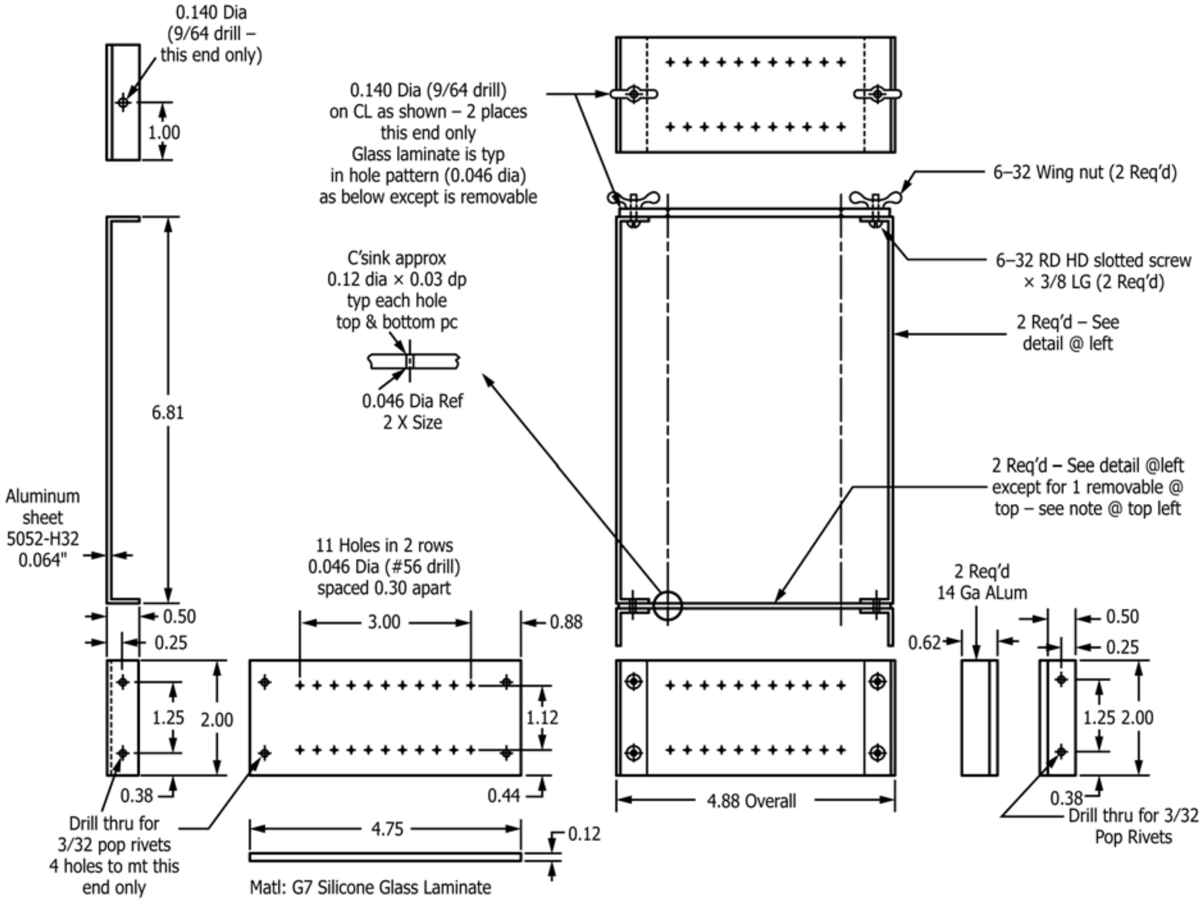
5.5.4 In most laboratories, the number of thermal endurance ovens is limited and, therefore, many different sets of specimens are thermally exposed in the same oven. All specimens are not necessarily removed each time the oven is opened. This extra temperature cycling will possibly have a degrading influence.

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

5.5.6 Vibration of specimens will have a degrading effect during the later thermal endurance 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 will possibly result in failure after the film insulated wire has been weakened by thermal deterioration and are more appropriately evaluated in insulation system tests.



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 A Specimen Holder

6. Apparatus

6.1 *Voltage Source* (see 8.3, 8.4, and 8.5).

6.2 *Oven* (see Specification D5423 Type 2).

6.3 *Device for Preparing Twisted Pair Specimens* (see Figs. 1 and 2).

6.4 *Specimen Holders* (see Figs. 3-5).

7. Test Specimens

7.1 *Preparation:*

7.1.1 Film-insulated round magnet wire having bare wire diameters ranging from 0.0113 to 0.1019 in. (0.287 to 2.588 mm) 10 to 29 AWG inclusive are evaluated as described in this test method. If the dimensions of the magnet wire are not known, determine them using Test Methods D1676.

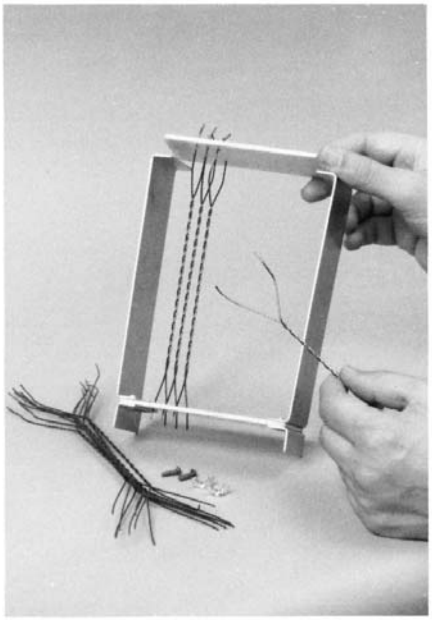


FIG. 4 A Specimen Holder

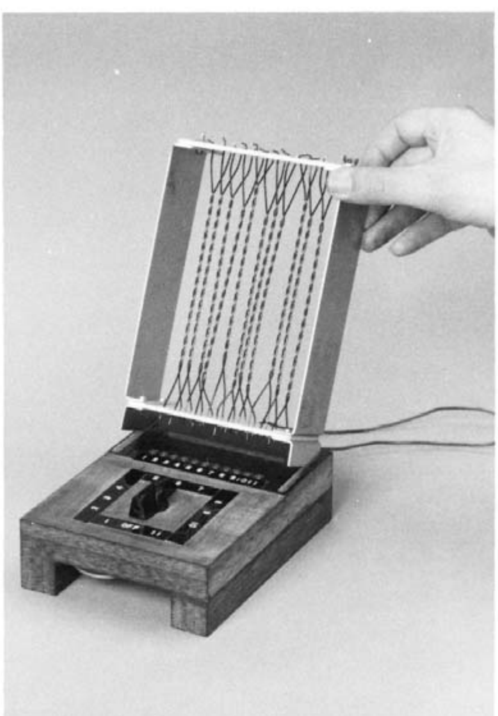


FIG. 5 A Specimen Holder and Electrical Connection Device

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 ± 0.25 in. (120 ± 6 mm) with a device similar to those shown in Figs. 1 and 2. The winding weight applied to the wire specimen while being twisted and the number of twists (full 360° rotations of the head of the twist maker) are given in Table 1.

7.1.3 If specimens are to evaluated with a varnish, see Test Method D3251.

7.2 *Number of Test Specimens*—The accuracy of the test results depends largely upon the number of test specimens exposed 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. It is permissible to evaluate a greater number of specimens if desired.

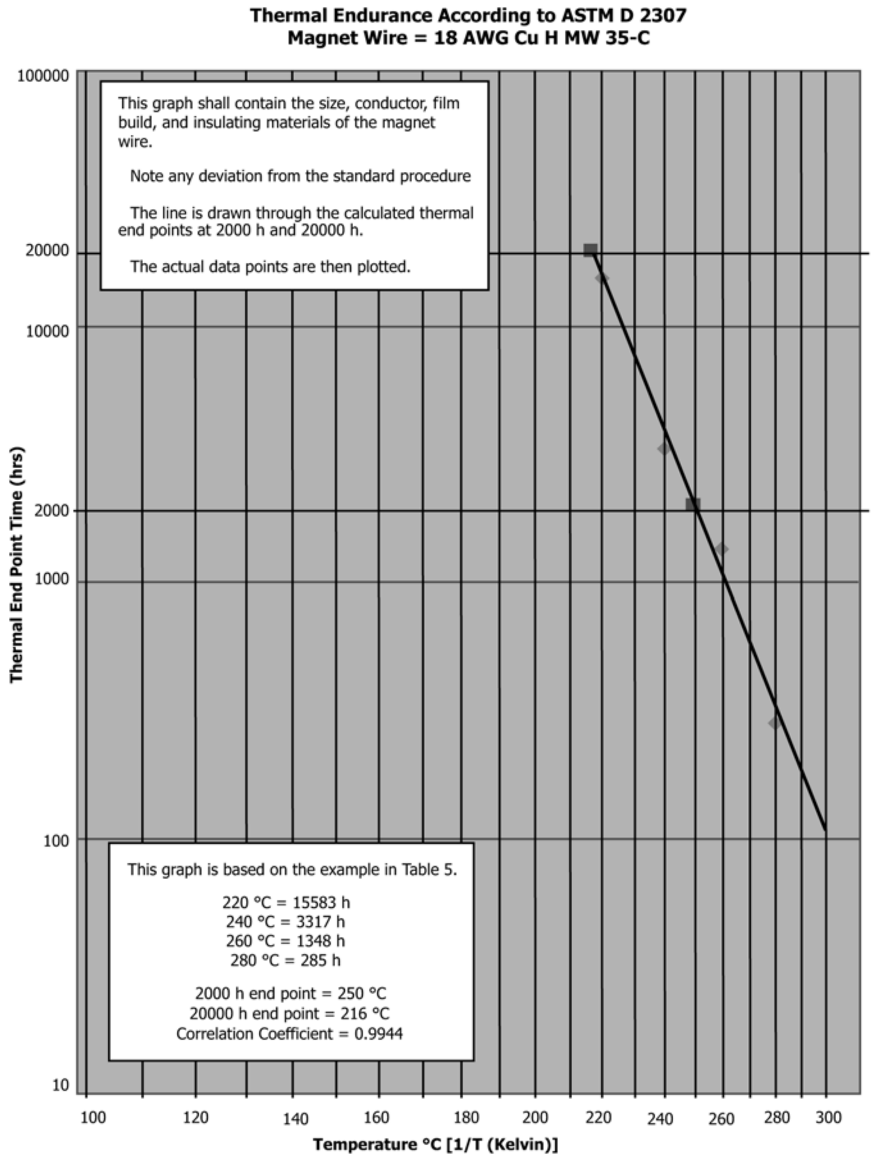
7.3 *Specimen Holder*—It has been found that individual handling of the twisted specimens will introduce premature failures. It is, therefore, mandatory that the specimens be placed in a suitable holder. Design the holder in a manner that will protect the twisted specimens from external mechanical damage and warpage. An example of a suitable holder is shown in Figs. 3 and 4. Construct the holder so as to allow for the electrical connection of the twists for the proof testing (see Fig. 5 for an example).

7.4 *Electrical Connection*—Provide a suitable electrical connection to the test specimens in the holder that will not induce mechanical stress to the specimens. Non-mechanical connections are preferred. A typical device is shown in Fig. 5. The specimens are connected to a voltage source as described in 8.3 and 8.4.

8. Procedure

8.1 Prior to the first exposure cycle, make sure all specimens pass the proof-voltage test (see Table 2). Expose the specimens at elevated temperatures in accordance with Table 3. Remove the specimens from the 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. It is permissible to extend Table 3 at the high end of the exposure temperature range to accommodate special high-temperature film insulations. The thermal endpoint time of the specimens will possibly 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 are possibly unreliable. Therefore, to ensure the number of cycles to failure will be within the parameters, adjust the exposure time. For example, if a set of test specimens has been exposed for eight cycles and less than half have failed, it is recommended that the exposure time should be approximately doubled, and if the test shows a 30 % or greater failure rate by the fourth cycle, it is recommended that the exposure time should be reduced by one-half. Expose test specimens to at least three temperatures. It is recommended that exposure temperatures 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 equally so that they cover a range of at least 40°C. The accuracy of the time to failure 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 exposure temperature must be at



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

FIG. 6 Example of a Regression Line Plot (Table 5)

TABLE 1 Tension and Number of Twists for Twisted Pair Construction

Nominal Bare Wire Diameter		Wire Size AWG[A]	Total Twists	Winding Weight on Specimens (± 2%)	
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.

least 5000 h. If the log average or median hours are less than 100, do not use the data. Use ovens of the forced-draft design conforming to Specification D5423 Type 2.

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

TABLE 2 Proof-Voltage Test

Difference Between the Bare Wire and Insulated Wire Diameters[A]		AC Test Voltage, V ± 5%
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

[A] For self-bonding magnet wires, the self-bonding layer is included in the film build thickness determination.

TABLE 3 Recommended Exposure Times in Days Per Cycle

Exposure 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	56
250				2	7	28	
240				4	14	56	
230			1	7	28		
220			2	14	56		
210		1	4	28			
200		2	7	56			
190	1	4	14				
180	2	7	28				
170	4	14	56				
160	7	28					
150	14	56					
140	28						
130	56						
120							

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 with 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 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. Failure Time Calculations

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 log average method as described in 9.2.2. 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 (see 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 shall 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 the Temperature Index, Correlation Coefficient, and Plotting Thermal Endurance

10.1 *Calculating the Thermal Index:*

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

$$L = Ae^{B/T} \tag{1}$$

where:

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

10.1.1.1 Eq 1 can be expressed as a linear function by taking logarithms as follows:

$$\log_{10}L = \log_{10}A + (\log_{10}e)\cdot\frac{B}{T} \tag{2}$$

let:

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

Then:

$$Y = a + bX \tag{3}$$

10.1.2 By the use of the method of least squares, the constants *a* and *b* are derived in terms of the experimental data obtained. These equations are as follows:

$$a = \frac{\sum Y - b\sum X}{N} \quad (4)$$

$$b = \frac{N\sum XY - \sum X\sum Y}{N\sum X^2 - \left(\sum X\right)^2} \quad (5)$$

where:

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

10.1.3 Knowing the constant *a* and the slope *b* of the regression line, calculate the temperature index at any required time interval as follows:

$$Y = a + bX \quad (6)$$

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

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

$$\text{Temperature Index at 2000 h in °C} = \frac{b}{3.3010 - a} - 273 \quad (9)$$

10.1.4 *Sample Calculation of Thermal Indices:*

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

10.1.4.2 In Table 5, column 1, under Temperature °C, list each temperature at which a set of specimens was tested.

TABLE 4 Commonly Used Test Temperatures in Degrees Celsius and the Corresponding Kelvin Temperature with its Reciprocal and Reciprocal Squared Values

NOTE 1—Calculations for X^2 are based on non-rounded values.

°C	K	$X = 1/T$, K^{-1}	$X^2 = 1/T^2$, K^{-2}
105	378	2.646×10^{-3}	6.999×10^{-6}
125	398	2.513×10^{-3}	6.313×10^{-6}
130	403	2.481×10^{-3}	6.157×10^{-6}
140	413	2.421×10^{-3}	5.863×10^{-6}
150	423	2.364×10^{-3}	5.589×10^{-6}
165	438	2.283×10^{-3}	5.212×10^{-6}
175	448	2.232×10^{-3}	4.982×10^{-6}
180	453	2.208×10^{-3}	4.873×10^{-6}
185	458	2.183×10^{-3}	4.767×10^{-6}
190	463	2.160×10^{-3}	4.665×10^{-6}
200	473	2.114×10^{-3}	4.470×10^{-6}
210	483	2.070×10^{-3}	4.287×10^{-6}
220	493	2.028×10^{-3}	4.114×10^{-6}
225	498	2.008×10^{-3}	4.032×10^{-6}
230	503	1.988×10^{-3}	3.952×10^{-6}
240	513	1.949×10^{-3}	3.800×10^{-6}
250	523	1.912×10^{-3}	3.656×10^{-6}
260	533	1.876×10^{-3}	3.520×10^{-6}
270	543	1.842×10^{-3}	3.392×10^{-6}
280	553	1.808×10^{-3}	3.270×10^{-6}
300	573	1.745×10^{-3}	3.048×10^{-6}
320	593	1.686×10^{-3}	2.844×10^{-6}

10.1.4.3 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 Kelvin (see also Table 4).

10.1.4.4 In the fourth column, according to 9.2.2, 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 ($Y = \log_{10}L$).

10.1.4.5 In the sixth column, list the products of *X* and *Y*.

10.1.4.6 In the seventh column list Y^2.

10.1.4.7 Provide summation for columns 2, 3, 5, 6, and 7, and enter the summation (indicated by $\sum$) at the bottom of the respective column.

10.1.4.8 At the bottom of column 5, below the sum, enter the value of the average of *Y*, and the value of the (average of $Y)^2$.

10.1.4.9 Indicate the number *N* (number of test temperatures used) on the worksheet.

10.1.4.10 Using the values obtained in 10.1.4.7 and 10.1.4.9, compute *b* (Eq 5) and *a* (Eq 4) in that order as shown above. The constant a will always be negative.

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

10.2 *Calculating the Correlation Coefficient—Linearity:*

10.2.1 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.

$$r = \sqrt{\frac{aY + bXY - N(\text{Avg } Y)^2}{Y^2 - N(\text{Avg } Y)^2}} \quad (10)$$

where:

N = number of test temperatures used, and
X, Y = the variables (see 10.2)

10.2.2 Using the example data in 10.1.4:

$$\text{Correlation Coefficient} - \text{Linearity } r = \quad (11)$$

$$\sqrt{\frac{a\sum Y + b\sum XY - N(\text{Avg } Y)^2}{\sum Y^2 - N(\text{Avg } Y)^2}} = 0.9944$$

10.2.3 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.

10.2.4 In the event that the correlation coefficient is less than 0.95, the data is said to be nonlinear and additional tests at other test temperatures are required. It is recommended that the new temperature point be 10°C below the previous lowest temperature point. When recalculating the temperature index and correlation coefficient, it is permissible for one temperature point to be deleted, starting with the highest temperature, provided that there are still three valid data points.

10.2.5 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 possibly indicates the following:

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

TABLE 5 Sample Calculations

NOTE 1—Calculations in Table 5 are based on non-rounded values

Temperature (°C)	$X = 1/T$	$X^2 = 1/T^2$	L (h)	$Y = \log_{10}L$	$XY = (\log_{10}L)/T$	Y^2
220	2.028×10^{-3}	4.114×10^{-6}	15583	4.193	8.504×10^{-3}	17.578
240	1.949×10^{-3}	3.800×10^{-6}	3317	3.521	6.863×10^{-3}	12.396
260	1.876×10^{-3}	3.520×10^{-6}	1348	3.130	5.872×10^{-3}	9.795
280	1.808×10^{-3}	3.270×10^{-6}	285	2.455	4.439×10^{-3}	6.026
$\sum$	7.661×10^{-3}	14.704×10^{-6}		13.299	25.678×10^{-3}	45.795
$N = 4$				Avg. Y = 3.324		
				(Avg. $Y)^2$ = 11.052		

$$b = \frac{N\sum XY - \sum X \sum Y}{N\sum X^2 - \left(\sum X\right)^2} = \frac{4 \times 25.678 \times 10^{-3} - 7.661 \times 10^{-3} \times 13.299}{4 \times 14.704 \times 10^{-6} - \left(7.661 \times 10^{-3} \times 7.661 \times 10^{-3}\right)} = 7633.4$$

$$a = \frac{\sum Y - b\sum X}{N} = \frac{13.299 - 7633.4 \times 7.661 \times 10^{-3}}{4} = -11.298$$

$$\text{Temperature Index at 20 000 h in °C} = \frac{b}{Y - a} - 273 = \frac{7633.4}{4.301 + 11.298} - 273 = 216.4°C$$

$$\text{Temperature Index at 2000 h in °C} = \frac{b}{Y - a} - 273 = \frac{7633.4}{3.301 + 11.298} - 273 = 249.9°C$$

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

10.2.6 It shall be noted that nonlinear results 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).

NOTE 1—For a more detailed discussion of the statistical analysis and to determine confidence limits, see the latest issue of IEEE 101.

10.3 *Plotting Thermal Endurance*—Present the thermal endurance data graphically by plotting the time to failure versus its respective exposure temperature on graph paper having a logarithmic time scale as the ordinate and the oven exposure temperature (expressed in °C but calculated as 1/K) as the abscissa (see Fig. 6).

10.3.1 Plot the temperature indices of 2000 and 20 000 h as derived using Eq 8 and 9 and draw a regression line through them. 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.

10.3.2 Plot the times to failure L at the respective temperatures on the same graph.

10.3.3 This graph shall be used for reference only and not for determining thermal indices. The thermal indices shall be determined by the calculations described in 10.1 and 10.2. While this graph is not accurate enough for the extrapolation of thermal indices, it does provide useful information as to the data points generated and the thermal characteristics of the material being evaluated.

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

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

11.1.4 The thermal indices as determined in 10.1.

11.1.5 The correlation coefficient and any data point substitutions or deletions used to correct for non-linearity.

12. Precision and Bias

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

	MW 15-C	MW 24-C
Average Temperature Index: °C	108.98	190.40
Standard Deviation: °C	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 correlation coefficient; linearity; magnet wire; temperature index; thermal endurance

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

SUMMARY OF CHANGES

Committee D09 has identified the location of selected changes to this test method since the last issue, D2307 – 07, that may impact the use of this test method. (Approved October 1, 2007)

(*1*) Corrected oven type requirement for this method to a Type 2 oven in 6.2.

Committee D09 has identified the location of selected changes to this test method since the last issue, D2307 – 05, that may impact the use of this test method. (Approved January 1, 2007)

(*1*) Replaced Fig. 3 and Fig. 6 with new images.