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Standard Test Method for Temperature-Resistance Constants of Alloy Wires for Precision Resistors[1]

This standard is issued under the fixed designation B84; 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 change of resistance with temperature of alloy wires used for resistance standards and precision resistors for electrical apparatus.

1.2 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.3 *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 become familiar with all hazards including those identified in the appropriate Material Safety Data Sheet (MSDS) for this product/material as provided by the manufacturer, to establish appropriate safety and health practices, and determine the applicability of regulatory limitations prior to use.*

2. Significance and Use

2.1 Procedure A covers the determination of the equation of the curve relating resistance and temperature where the curve approximates a parabola. This test method may be used for wire of any metal or alloy over the temperature interval appropriate to the material.

2.2 Procedure B covers the determination of the mean temperature coefficient of resistance for wire of any metal or alloy over the temperature interval appropriate to the material.

3. Apparatus

3.1 The apparatus for making the test shall consist of one or more baths for maintaining the specimen at the desired temperatures; thermometers for measuring the temperatures of the baths; and suitable means for measuring the resistance of the specimen. Details of the apparatus are given in Sections 4 to 6.

4. Baths

4.1 Baths for use from −65 to +15°C may consist of toluol, or equivalent.

4.2 Baths for use above 15 to 250°C may consist of chemically neutral oils with a low viscosity, having a flash point at least 50°C higher than the temperature of use.

4.3 The liquid in these baths shall be of such quantity and so well stirred that the temperature in the region occupied by the specimen and the thermometer will be uniform within 0.5°C for any temperature between −65 and +100°C, and within 1.0°C for any temperature above 100 to 250°C. If the temperature range is less than 100°C, the uniformity of temperature shall be proportionately closer.

NOTE 1—It is recommended that a solvent bath at room temperature shall be used to rinse specimens before immersion in any temperature bath.

5. Temperature Measurement Apparatus

5.1 The temperature shall be measured to an accuracy of ±0.5°C, or 1 % of temperature range, whichever is smaller.

6. Resistance Measurement Apparatus

6.1 The change of resistance of the specimen shall be measured by apparatus capable of determining such changes to 0.001 % of the resistance of the specimen if the temperature range is 50°C or more. If the temperature range is less than 50°C, the accuracy of the resistance change measurements shall be correspondingly greater.

6.2 The connections from the specimen to the measuring device shall be such that changes in the resistance of these connections due to changes in their temperature do not appreciably affect the measurement of the change in resistance of the specimen.

6.3 The temperature of the measuring apparatus shall not change during the test by an amount sufficient to introduce appreciable errors in the results. With apparatus of good quality, a change in 1°C in room temperature is allowable.

6.4 The test current shall not be of such a magnitude as to produce an appreciable change in resistance of the specimen or measuring apparatus due to the heating effect. To determine experimentally that the test current is not too large, the

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specimen may be immersed in a bath having a temperature at which it has been found that the wire has a relatively large change in resistance with temperature. Apply the test current and maintain until the resistance of the specimen has become constant. Then increase the current by 40 % and maintain at this value until the resistance has again become constant. If the change in resistance is greater than 0.01 %, the test current is too large and shall be reduced until the foregoing limitation is reached.

6.5 The measurements shall be made in such a way that the effects of thermoelectromotive forces and parasitic currents are avoided. When these effects are small, the resistance of the specimen may be obtained by either of the following methods:

6.5.1 Obtain the galvanometer zero with the galvanometer key open. Balance the bridge both with the direct and reversed connection of the battery, the average value of the two results being the resistance of the specimen.

6.5.2 Obtain the zero of the galvanometer with the galvanometer key closed and the battery key opened. A single balance of the bridge is then sufficient to obtain the resistance of the specimen.

7. Sampling

7.1 Take one test specimen from each continuous length of the material to be tested.

8. Test Specimen

8.1 The test specimen shall be of a length that will give a resistance that can be measured to the required accuracy.

8.2 If the wire is insulated, it may be wound in a circular, open coil not less than 50 mm in diameter.

8.3 If the wire is not insulated, it may be wound on an insulating form of a type that will not introduce strains in the wire when subjected to temperature changes.

8.4 The tension used in winding shall be no more than sufficient to produce a neat coil of insulated wire or to prevent the touching of adjacent turns when bare wire is wound on an insulating form.

8.5 For fine wires of sufficiently high-resistivity alloys, straight wire specimens may be used. Precautions should be taken to avoid the introduction of strains in the sample during preparation.

9. Terminals

9.1 For specimens having a resistance so large that the resistance of the leads is negligible, a copper wire may be brazed, soldered, or welded to each end of the specimen for use as a terminal. The resistance of the copper terminals shall be less than 0.02 % of the resistance of the specimen.

9.2 If the resistance of the specimen is less than 10 Ω, so that it is necessary to use both current and potential terminals in measuring the resistance, two copper wires may be brazed, soldered, or welded to each end of the specimen for use as terminals. The terminals shall be placed so that the measured potential does not include the potential drop in the current connections.

9.3 In coils made of fine wire where there is not sufficient rigidity in the coil itself to furnish a satisfactory support for the terminals, short lengths of thin glass or ceramic rods may be found across the coil to act as struts and furnish an anchorage for the terminals.

10. Preliminary Treatment of Specimen

10.1 The finished specimen shall be subjected to a baking treatment as necessary to stabilize the resistance of the specimen. For manganin the treatment shall be at 140 ± 10°C continuously for a period of 48 h.

11. Procedure A

11.1 Connect the test specimen in the measuring circuit and submerge entirely in the bath. For a check on the constancy of the specimen, make an initial resistance measurement at 25°C. Raise the temperature of the bath or transfer the specimen to a bath maintained constant at the highest temperature at which measurements are to be made. When the specimen has attained a constant resistance, record the reading of the measuring device and the temperature of the bath.

11.2 Decrease the temperature of the test specimen to the next lower temperature either by cooling the bath and maintaining it constant at the next lower temperature, or by removing the specimen to another bath maintained at the lower temperature. When the resistance of the specimen has become constant, again make observations of resistance and temperature.

11.3 In this manner, make a series of determinations of the change of resistance with temperature for the desired descending temperature range, measurements being taken at intervals of approximately 10 % of the temperature range or any temperature interval specified by agreement between producer and consumer.

11.4 Test at not less than four temperatures.

11.5 Note the temperature of the measuring apparatus at frequent intervals during the test of each specimen.

12. Procedure B

12.1 See Section 11, except 11.4. Tests shall be made at not less than three temperatures, including 25°C.

13. Resistance-Temperature Equation

13.1 Express the results in terms of the constants in an equation of the following form:

$$R_t = R_{25}\left[1+\alpha(t-25)+\beta(t-25)^2\right] \tag{1}$$

where:

R_t	=	resistance of the specimen in ohms at temperature, °C, t,
R_{25}	=	resistance of the specimen in ohms at the standard temperature of 25°C,
t	=	temperature of specimen, °C, and
α *and* β	=	temperature-resistance constants of the material.

Temperature of maximum or minimum resistance

$$= 25°C - (\alpha/2\beta)$$

NOTE 2—This equation will yield either a maximum or a minimum, depending on which exists in the temperature range in question. However, this equation is normally used for those alloys such as manganin, having a temperature-resistance curve approximating a parabola with a maximum near room temperature.

14. Calculation of Constants

14.1 The values of α, β and R_{25} may be determined by selecting the measured values of R_t at three well-separated temperatures, inserting the values of R_t and t in the above equation to form three equations, and solving simultaneously the three equations for R_{25}, α, and β.

14.2 When the measurements have not been made at exactly 25°C, or at other suitable temperatures, the calculation may be simplified by plotting a curve from the observed values of resistance and temperature, from which curve R_{25} may be read directly. Two additional points may then be selected on the curve, preferably one at t_1, at least 5°C below the reference temperature of 25°C, and a second temperature, t_2 near the highest temperature measured but satisfying the following relation:

$$K(25 - t_1) = t_2 - 25 = K\Delta t \quad (2)$$

where K is, for ease of calculation, generally taken as an integer.

NOTE 3—*Example:* If t_1 is 10°C below the reference temperature then t_2 should be 10 or 20 or 30°C etc., above the reference temperature for greatest ease of calculation, so that $K = 1$ or 2 or 3, respectively.

14.3 If R_1 is the resistance at the temperature t_1, and R_2 is the resistance at the temperature t_2, then:

$$\alpha = [(R_2 - R_{25}) - K^2(R_1 - R_{25})]/R_{25}K(K+1)\Delta t \quad (3)$$

$$\beta = [K(R_1 - R_{25}) + (R_2 - R_{25})]/R_{25}K(K+1)(\Delta t)^2 \quad (4)$$

If $K = 1$, this simplifies to:

$$\alpha = (R_2 - R_1)/2R_{25}\Delta t \quad (5)$$

$$\beta = (R_1 + R_2 - 2R_{25})/2R_{25}(\Delta t)^2 \quad (6)$$

If, instead of measuring the actual resistances at the different temperatures, the change in resistance relative to the resistance at 25°C is measured, the above equations take a slightly different form, as follows: Let ΔR_1 represent the change in resistance in ohms per ohm in going from 25°C to t_1, and ΔR_2 the similar change in going from 25°C to t_2. That is:

$$\Delta R_1 = (R_1 - R_{25})/R_{25} \quad (7)$$

and

$$\Delta R_2 = (R_2 - R_{25})/R_{25} \quad (8)$$

Then

$$\alpha = (\Delta R_2 - K^2\Delta R_1)/K(K+1)\Delta t \quad (9)$$

$$\beta = (K\Delta R_1 + \Delta R_2)/K(K+1)(\Delta t)^2 \quad (10)$$

If $K = 1$, this simplifies to:

$$\alpha = (R_2 - \Delta R_1)/2\Delta t \quad (11)$$

$$\beta = (\Delta R_1 + \Delta R_2)/1(\Delta t)^2 \quad (12)$$

NOTE 4—A useful alternative method of calculation is presented as follows: The resistance-temperature equation is referred to 0°C, and relative resistance values are used. For example, over the useful range from 15 to 35°C, the resistance-temperature curve of manganin is parabolic and of the form:

$$P_t = P_0 + At + Bt^2 \quad (13)$$

where:

P_t = %, ratio of the resistance of the specimen at t °C to the resistance of the standard resistor at 25°C, expressed in percent,

P_0 = %, ratio of the resistance of the specimen at 0°C to the resistance of the standard resistor at 25°C, expressed in percent, and

A and B are constants calculated from resistance measurements made at different temperatures. One method of measurement used in production testing is to compare the resistance of the test sample to that of a stable resistor of known characteristics maintained at reference temperature 25°C. The resistance is approximately the same as the test sample and measurements usually are made directly in percentages (for example, 100.008 %). If measurements are made at four temperatures t_1, t_2, t_3, and t_4 between 15 and 35°C, and the corresponding ratios of test sample resistance to standard resistor are measured in percentages as P_1, P_2, P_3, and P_4, then the constants A and B, the peak temperature, and temperature coefficient may be calculated from the following equations:

$$A = \frac{1}{2}\left[\frac{P_3 - P_1}{t_3 - t_1} + \frac{P_2 - P_1}{t_4 - t_1} - (t_3 + t_r + 2t_1)\right] \quad (14)$$

$$B = \frac{\frac{P_3 - P_1}{t_3 - t_1} + \frac{P_4 - P_1}{t_4 - t_1} - 2\frac{P_2 - P_1}{t_2 - t_1}}{t_3 + t_4 - 2t_2} \quad (15)$$

The peak temperature is – (A/2B) and the temperature coefficient between temperature t and the peak temperature in percent per degree Celsius is (A + 2Bt)/2. Then

$$\alpha = (A + 50B)/100 \quad (16)$$

$$\beta = B/100 \quad (17)$$

15. Procedure A—Report

15.1 Report the following information:

15.1.1 Identification of specimen,

15.1.2 Description of material and its insulation,

15.1.3 Length of wire in specimen and approximate resistance,

15.1.4 Tabular list of resistances and temperatures in the order taken,

15.1.5 Temperature of measuring apparatus and room at start and finish of test,

15.1.6 Values of t and Δ R used in calculating α and β,

15.1.7 Values calculated for the temperature-resistance constants α and β, and

15.1.8 Temperature of the specimen at which the change of resistance with temperature is zero, if such occurs within the measured range.

16. Procedure B—Report

16.1 Report the following information:

16.1.1 Identification of specimen,

16.1.2 Description of material and its insulation,

16.1.3 Length of wire in specimen and approximate resistance,

16.1.4 Tabular list of resistance and temperatures in the order taken,

16.1.5 Temperature of measuring apparatus and room at start and finish of test, and

16.1.6 Values of temperature coefficient of resistance in microhms per ohm per degree Celsius or parts per million per

TABLE 1 Illustrative Form for Reporting Test Data and Calculations

NOTE 1—The following table, with test values inserted for purpose of illustration, is only a suggested form for recording test data and calculations on temperature-resistance characteristics.

Material	Manganin, Specimen No. 1. From Shipment Received ... Jan. 14, 1936
Maker	John Doe
Size	0.010 in. Approximate Resistance of Specimen ... 100 Ω
Insulation	Double Silk. Length of Wire ... 11.4 m.

Record of Test

Order of Measurement	Temperature, °C	Resistance, [A] Ω	$\Delta R_t \times 10^{-6} = [(R_t - R_{25})/R_{25}] \times 10^{-6}$
1 [B]	25	99.8743	...
2	80	99.7336	−1403
3	65	99.7936	−803
4	50	99.8391	−348
5	30	99.8671	−68
6	25	99.8717	−22
7	20	99.8739	0
8	15	99.8735	−4
9	25	99.8707	−32
10 [B]		99.8739	...

[A] If the method of measurement is such that ΔR_t is measured directly, this column may be omitted.
[B] Indicates stability only, not used in calculation.

Calculations

Original: Temperature, °C	$\Delta R_t \times 10^{-6}$	Supplementary: Temperature, °C	$\Delta R_t \times 10^{-6}$
25	0	25	0
15	−32	20	−4
65	−803	80	−1403
$\Delta t = 10$		$\Delta t = 5$	
$K = 4$		$K = 11$	
$\alpha = -1.46$		$\alpha = -1.40$	
$\beta = -0.47$		$\beta = -0.44$	

Average $\alpha = -1.4 \times 10^{-6}$
Average $\beta = -0.45 \times 10^{-6}$
Temperature for maximum resistance = 25°C (α/2β) = 23.4°C.

degree Celsius. These values shall be calculated for each test temperature, using the following equation:

$$\text{Mean temperature coefficient of resistance over specified temperature interval} = \left[(R_1 - R_{25})/R_{25}(T_1 - 25)\right] \times 10^6 \quad (18)$$

where:

R_1 = resistance of specimen at test temperature, Ω,
R_{25} = resistance of specimen at 25°C, Ω, and
T_1 = temperature of the bath, °C.

17. Record

17.1 The measurements shall be recorded on a data sheet similar to that shown in Table 1.

18. Precision and Bias

18.1 The instrumentation and operator's skill play a large part in the precision and bias attainable. There are no data available to determine a precision and bias figure for this test method.

19. Keywords

19.1 resistance change; resistance constants; resistors; resistor wire; temperature coefficient; temperature resistance

APPENDIX

(Nonmandatory Information)

X1. ALTERNATIVE COMPUTATIONS

X1.1 Another useful alternative for computing the value of α and β is: For a given piece of manganin, if the resistances at three different appropriate temperatures (one of which is 25°C) are known, they may be substituted into the equation of Section 11 to form two equations. These two equations may be solved simultaneously for α and β as follows:

$$\beta = \frac{\frac{(P_n - P_{25})}{(T_n - 25)} - \frac{(P_m - P_{25})}{(T_m - 25)}}{(T_n - T_m)}$$

$$\alpha = [(P_n - P_{25})/(T_n - 25)] - \beta(T_n - 25)$$

where:

P_n = resistance difference from a nominal value (expressed in parts per million) at temperature T_n (°C),

P_m = resistance difference from a nominal value (expressed in parts per million) at temperature T_m (°C),

P_{25} = resistance difference from a nominal value (expressed in parts per million) at 25°C, and

α *and* β = constants (α expressed in ppm/°C; β in ppm/(°C)^2).

X1.1.1 As before, the temperature of peak resistance in degrees Celsius is:

$$T_{max} = 25 - (\alpha/2\beta)(dc)$$

X1.1.2 The temperature coefficient (T.C.) in parts per million per degree Celsius at any temperature is:

$$T.C. = \alpha + 2\beta(T - 25)$$

X1.1.3 The resistor whose temperature coefficient data is being determined is measured at three temperatures as follows:

	T_m	T_{25}	T_n
Wire-grade manganin	17°C	25°C	32°C
Shunt-grade manganin	40°C	25°C	50°C

All temperatures must be held to ±0.2°C.

X1.1.4 The resistance values are measured and recorded in terms of differences from another resistor (such as an NIST or Reichenshalt design) expressed in parts per million. The values are designated P_m and P_n corresponding to T_m and T_n.

X1.1.5 The resolution of the resistance determination must be 1 ppm or better for wire-grade manganin. The resolution of the resistance determination must be 5 ppm or better for shunt-grade manganin.

X1.1.6 After the resistance values at the three temperatures have been obtained, the values and the temperatures are substituted into the equations for β and α to obtain the numerical values of β and α.

X1.1.7 If the determination of α and β are to conform with this specification, measurements at four temperatures will have to be made. The computation of α and β shall be made using three of the four temperatures and their corresponding resistance differences. A second computation of α and β shall be made using three of the four temperatures, one of which is the one not used in the preceding section. This computation of α and β using different T_m's (or T_n's) will ensure that no mistake has been made. Differences between the two values of either α or β shall not exceed 10 %.