Designation: B114 – 07 (Reapproved 2013)

Standard Test Method for Temperature-Resistance Constants of Sheet Materials for Shunts and Precision Resistors[1]

This standard is issued under the fixed designation B114; 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 the determination of the change of resistance with temperature of sheet materials used for shunts and precision resistors for electrical apparatus. It is applicable to materials normally used in the temperature range of from 0 to 80°C.

1.2 The values stated in inch-pound units are to be regarded as the standard. The metric equivalents of inch-pound units may be approximate.

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. Referenced Documents

2.1 *ASTM Standards:*[2]

B84 Test Method for Temperature-Resistance Constants of Alloy Wires for Precision Resistors

3. Significance and Use

3.1 This test method covers the determination of the change of resistance with temperature for precision resistors and shunts made from sheet materials.

3.2 Materials normally used in the temperature range from 0 to 80°C may be tested using this test method.

4. Test Specimen

4.1 The test specimen shall be of such dimensions that its electrical resistance can be measured to the required accuracy.

NOTE 1—Measurements are simplified if the specimen has a resistance of 0.01 Ω or more. The specimen may be bent in the form of a "U" to facilitate handling.

5. Terminals

5.1 A current terminal shall be attached to each end of the specimen. These terminals shall be either soldered or clamped in such a manner that there will be no change of current distribution in the specimen during the test.

5.2 Potential terminals, one at each end, shall be located at a distance not less than two times the width of the specimen from the current terminals. These terminals shall be attached at the center of the width of the specimen either by soldering to ears cut out of the specimen (Note 2) as shown in Fig. 1 or by clamps, each of which presses a single sharp point into the material.

NOTE 2—The ears shall be cut so that they are about ½ in. (12.7 mm) in length and ⅛ in. (3.2 mm) in width. The cut shall be clean and free from slivers at the junction of the ear and the specimen. Before cutting the ears, it is desirable to drill two small holes with a sharp drill where the ear will be jointed to the specimen.

6. Preliminary Treatment for Manganin Samples

6.1 In the case of manganin materials, after all the mechanical work has been finished, the specimen shall be given one heat treatment of 48 h at 140 ± 5.0°C and then cooled to room temperature.

6.2 The specimen shall then be given a dip in a nitric acid solution (50 %) to remove the copper film (which can be judged by the color of the specimen) and then thoroughly scrubbed in running water.

7. Apparatus

7.1 The apparatus for making the test shall consist of one or more baths for maintaining the specimen at the desired

[1] This test method is under the jurisdiction of ASTM Committee B02 on Nonferrous Metals and Alloys and is the direct responsibility of Subcommittee B02.10 on Thermostat Metals and Electrical Resistance Heating Materials.

Current edition approved May 1, 2013. Published May 2013. Originally approved in 1938. Last previous edition approved in 2007 as B114 – 07. DOI: 10.1520/B0114-07R13.

[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.

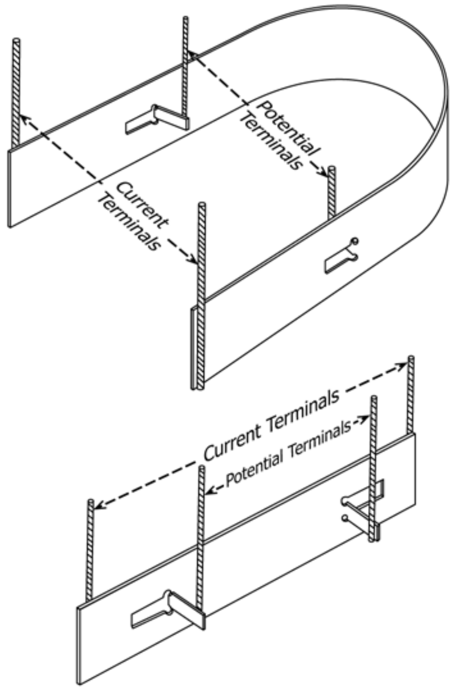

FIG. 1 Test Specimen Showing Terminal Connections

temperature, thermometers for measuring the temperatures of the baths, and suitable means for measuring the resistance of the specimen.

8. Baths

8.1 Each bath shall consist of chemically neutral oil. The oil shall be of such quantity and so well stirred that the temperature in the region occupied by the specimen and the thermometer shall be uniform within 0.2°C for any temperature between 0 and 80°C.

8.2 In an automatically controlled bath, the temperature of the bath at any time during the test at any temperature level shall not differ from its mean temperature by more than 0.2°C. In a manually controlled bath, the rate of change of temperature shall not exceed 0.2°C/min.

9. Temperature Measurement

9.1 The temperature shall be measured by a calibrated temperature measuring device of suitable precision and accuracy. The thermometer shall have sufficient sensitivity to indicate temperature changes of 0.1°C. It shall be sufficiently accurate to measure temperature differences to 0.2°C in the range from 0 to 80°C.

10. Resistance Measurements

10.1 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. A Kelvin double bridge, digital ohmmeter, or equivalent is suitable for this purpose (see Appendix X1).

10.2 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 of 1°C in its temperature is allowable.

10.3 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. The dimensions of the specimen should be such that the power dissipated shall not exceed 0.02 W/in.^{2} (0.003 W/cm^2) of exposed surface. To determine experimentally that the test current is not too large, the specimen may be immersed in a bath having a temperature at which it has been found that the sheet has a relatively large change in resistance with temperature. The test current shall be applied and maintained until the resistance of the specimen has become constant. The current shall then be increased by 40 % and maintained at this value until the resistance has again become constant. If the change in resistance is greater than 0.001 %, the test current is too large and shall be reduced until the foregoing limitation is reached.

10.4 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 when measured by a Kelvin bridge may be obtained by either of two methods. In the first method, the galvanometer zero shall be obtained with the galvanometer key open. The bridge shall be balanced both with the direct and reversed connection of the battery, the average value of the two results being the resistance of the specimen. In the second method, the zero of the galvanometer shall be obtained with the galvanometer key closed and the battery key open. A single balance of the bridge is then sufficient to obtain the resistance of the specimen.

11. Procedure

11.1 Connect the test specimen in the measuring circuit and submerge entirely in the oil bath. For a check on the constancy of the specimen, make an initial resistance measurement at room temperature. Raise the temperature of the oil bath or transfer the specimen to a bath maintained constant at the highest temperature at which measurements are to be made. When the test 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 temperatures 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.

11.4 Take measurements at a sufficient number of temperatures to determine the characteristics of the material. In order to calculate a resistance-temperature equation, tests at three temperatures are required. If an independent check is to be made, make observations of at least five temperatures. For plotting a curve, six or more observations are generally made.

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

12. Resistance-Temperature Equation

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

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

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 – (α/2β)

NOTE 3—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.

13. Calculation of Constants

13.1 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 preceding section equation to form three equations, and solving simultaneously the three equations for R_{25}, α, and β.

13.2 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 4—*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.

13.3 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:

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

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

NOTE 5—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,% ,
P_0 = ratio of the resistance of the specimen at 0°C to the resistance of the standard resistor at 25°C, %, 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

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

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

14. Report

14.1 Report the following information:

14.1.1 Identification of specimen,

14.1.2 Description of material,

14.1.3 Total length of specimen,

14.1.4 Approximate resistance and distance between potential terminals,

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.

Apparatus	Kelvin bridge for comparing the specimen with standard resistor
Standard resistor	No. 38472, 0.0100000 Ω made by Richard Roe
Ratio coils	A = 1000; B = 1000
Material	Manganin, Specimen No. 1. From Shipment Received .... Jan. 14, 1937
Maker	John Doe
Size	0.020 by 3 by 72 in. Approximate Resistance of Specimen .... 0.01 Ω

RECORD OF TEST

Time	Temperature, °C			Bridge Reading			Resistance of Specimen, Ω	Change in Resistance,[A] ppm
	Room	Standard	Specimen	Plus	Minus	Average		
10:00	25.0	25.0	25.0	1000.00	1000.02	1000.01	0.0100001[B]	...
10:30	25.0	25.0	80.2	999.60	999.62	999.61	0.0099961	–390
10:45	25.0	25.0	65.3	999.81	999.82	999.82	0.0099982	–180
11:00	25.0	25.0	49.8	999.98	999.98	999.98	0.0099998	–20
11:15	25.1	25.1	35.1	1000.02	1000.04	1000.03	0.0100003	+ 30
11:30	25.1	25.1	30.0	1000.02	1000.02	1000.02	0.0100002	+ 20
11:45	25.2	25.1	25.0	1000.00	999.99	1000.00	0.0100000	0
12:00	25.4	25.1	20.2	999.94	999.95	999.94	0.0099994	–60
12:15	25.5	25.2	15.0	999.88	999.88	999.88	0.0099988	–120
1:00	25.5	25.3	25.1	1000.00	1000.00	1000.00	0.0100000[B]	...

[A] Change in resistance based on the resistance at 25°C.

[B] These values are used for checking the stability only. If these values show a change of more than 0.002 %, then the preliminary treatment prescribed in Section 6 should be repeated

(*1*) Maximum change in resistance, 420 ppm, or 0.042 % between 35 and 80°C.

(*2*) Curve (see Fig. 2).

(*3*) Calculation of the constants in the resistance-temperature equation:

Original: Temperature, °C	$\Delta R_t \times 10^{-6}$	Supplementary: Temperature, °C	$\Delta R_t \times 10^{-6}$
25	0	25	0
15	–120	20	–60
65	–180	80	–390

Original: $\Delta t = 10$, $K = 4$, $\alpha = +8.7 \times 10^{-6}$, $\beta = -0.33 \times 10^{-6}$

Supplementary: $\Delta t = 5$, $K = 11$, $\alpha = +10.4 \times 10^{-6}$, $\beta = -0.32 \times 10^{-6}$

Average $\alpha = +9.6 \times 10^{-6}$

Average $\beta = -0.33 \times 10^{-6}$

Temperature for maximum resistance = 25°C – ($\alpha/2\beta$) = 25°C – (+ 9.6 ⁄ –0.66) = 39.5°C

14.1.5 Tabular list of resistances or changes in resistance and temperatures in the order taken,

14.1.6 Temperature of measuring apparatus and room at start and finish of the test,

14.1.7 Temperature of the specimen at which the change of resistance with temperature is zero (“peak temperature”), if such occurs within the measured range, and

14.1.8 Results expressed in one of the forms given in Section 15.

15. Record

15.1 The results shall be reported in one of the following forms and recorded on a data sheet similar to that shown in Table 1 and Fig. 2.

15.1.1 The maximum percentage change within the temperature range, or

15.1.2 A curve, plotted with temperature as abscissas, and the percentage or parts per million change in resistance as ordinates, or

15.1.3 The constants, α, β, etc., in a resistance-temperature equation may be calculated from the data and recorded as the constants of the temperature-resistance curve.

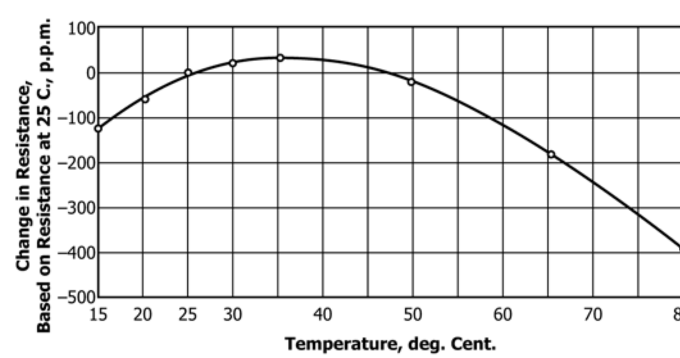

FIG. 2 Temperature-Resistance Curve of Sheet Manganin (Plotted from Data in Table 1)

16. Precision and Bias

16.1 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.

17. Keywords

17.1 resistance change; resistance constants; resistors; sheet resistors; shunts; temperature coefficient; temperature resistance

APPENDIX

(Nonmandatory Information)

X1. THE KELVIN DOUBLE BRIDGE

X1.1 There are several methods by which the Kelvin bridge (Fig. X1.1) may be so balanced that the ratio of the unknown to the standard is the same as the ratio of the two arms. The following method is indicated as being a satisfactory method for specimens having a resistance of 0.01 Ω or more.

X1.1.1 It is important that all the resistances except the ratio arms shall be kept as small as possible. In particular r_1, r_2, r_3, and r_4 should be less than 0.01 of the resistance of the ratio arms. The resistance of the connection between *X* and *N* should be less than the sum of *X* and *N*.

X1.1.2 The balance is made by a series of approximations. The two sets of ratio arms, *A, B,* and *a, b,* should have the same values and, whenever adjusted, the two should be adjusted simultaneously so that at all times $A = a$ and $B = b$. The bridge must be adjusted under three different conditions. These adjustments may be made in the following order:

X1.1.2.1 With switches S_1 and S_2 open, balance with double ratio dials, *A* and *a*,

X1.1.2.2 With S_1 open and S_2 closed, balance by adjusting the balancing resistor r_1, and

X1.1.2.3 With S_2 open and S_1 closed, adjust r_2.

X1.1.3 This cycle must be repeated until no change in the double ratio dials is required at the end of the cycle over that at the beginning.

X1.1.4 When the above balances have been obtained the resistance *X* of the unknown is represented by the equation:

$$X = N \cdot a/b$$

However, to determine the effect of temperature it is not necessary that the value of *N* should be known, for if *b* and *N* are kept constant and *a* changed as the resistance of *X* is changed because of change in temperature, then the percentage change in *X* is the same as the percentage change in *a*.

X1.1.5 In making the balance the resistors r_1 and r_2 are adjusted although these do not in any way enter into the final equation. Hence, any simple type of adjustable resistor is entirely satisfactory. In practice many laboratories use merely a short piece of copper wire, one terminal of which is held under a binding post. The resistance adjustment is made by loosening the binding post and sliding the copper wire as required to increase or decrease the resistance.

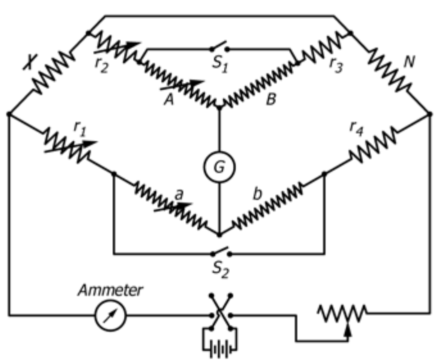

FIG. X1.1 Diagram of Kelvin Double Bridge