A SURVEY OF THERMOMETRIC CHARACTERISTICS OF RECENTLY PRODUCED ALLEN-BRADLEY / OHMITE RESISTORS*

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Temperature calibration measurements on Allen-Bradley/Ohmite carbon composition resistors of recent manufacture have been carried out. It has been found that the characteristic resistance vs. temperature behavior reported originally by J. R. Clement and his collaborators is no longer followed, presumably due to changes in manufacturing technique. The newer resistors increase in resistance less rapidly (than the older ones) as the temperature is decreased. Thus, they are more useful over a wider range of temperature, especially when measured in a bridge network in which bridge sensitivity decreases rapidly as resistance increases. Attempts to parameterize the resulting R vs. T curves from the room and liquid nitrogen temperature resistances will be reported. A report will also be made on the reproducibility and stability of the newer thermometers.

INTRODUCTION

Carbon composition resistors of the most common variety, and costing under $.25 each, have for many years been used as cryogenic thermometers over a wide range from room temperature down to below 1 K. Perhaps the greatest impetus to the use of carbon resistance thermometers came from the early work of Clement and Quinnell.[1] In this work, Allen-Bradley resistors were used, and it was reported that the thermometric calibration of a given resistor was reproducible from run to run. Later Plumb and Edlow[2] established the reproducibility of these resistors to an even higher precision, although a non-reproducibility myth seems to have been propagated and persists to this day. Still later, Weinstock, Guenther and Schleicher[3] reaffirmed Plumb and Edlow's conclusion on 12 and 68 Ω, 1/8 watt Ohmite resistors which showed no change in calibration over a period of about 18 months and several cycles between room and liquid helium temperatures. It should be pointed out that Ohmite resistors were used for the simple reasons that they were more readily available then Allen-Bradley resistors, they have the same thermometric characteristics as the Allen-Bradley ones, and a phone call to the Ohmite Corporation in Evanston, Illinois confirmed the suspicion that both brands are manufactured by the same manufacturer, namely Allen-Bradley.

About five years ago a change in production techniques by Allen-Bradley resulted in resistors whose variation in resistance with temperature shows modification from those produced earlier. It is the purpose of the current investigation to provide information on the thermometric properties of these newly produced resistors. Both Ohmite and Allen-Bradley brand resistors of 1/8 watt rating and varying in nominal value from 12 to 5600 Ω have been calibrated over a temperature range from 3 to 300 K. Measurements were carried out over a period of about two months with most of the test resistors cycled ten times between room and liquid helium temperatures.

Apparatus

All specimens were mounted at the same height on a 1.9 cm(0.75 in) diameter within a copper cylinder of 2.5 cm(1.0 in) outer diameter. Each resistor was grounded electrically and thermally to the 1.6 cm(0.62 in) thick top plate of the copper cylinder by a tight mechanical connection. The remaining portion of the cylinder, machined from electrolytic grade copper, fitted closely around this top plate, and was locked to it thermally and mechanically by vacuum grease and three mounting screws.

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Electrical leads were removed to room temperature through the interior of a centrally positioned 0.025 mm(10 mil) wall, 1.0 cm(0.37 in) diameter stainless steel tube which supports the copper cylinder. The height of the cylinder could be altered and fastened at a given height (either below or above the liquid helium) by utilization of a sliding seal vacuum coupling mounted on the top flange of the test dewar.

Temperatures were determined (1) between 3 and 4.2 K by measuring [4] He ɒor pressure with a Wallace and Tiernan aneroid manometer; (2) between 4.2 and 40 K by using a calibrated Texas Instruments germanium thermometer; and (3) between 13.2 and 300 K by using a calibrated Rosemount Engineering Company platinum resistance thermometer. The germanium and platinum thermometers were mounted in the same fashion as the test resistors. The overlap and continuation of the R vs. T data obtained seems to indicate that the above mentioned temperature standards are self-consistent and that the two calibrated thermometers are always at the same equilibrium temperature as the test resistors. A check of the calibration of the platinum thermometer at the normal boiling points of liquid nitrogen and liquid helium and of the germanium thermometer at the liquid helium normal boiling point, show that these standard thermometers have the values as stated by their manufacturers to within the precision of the resistance measurement.

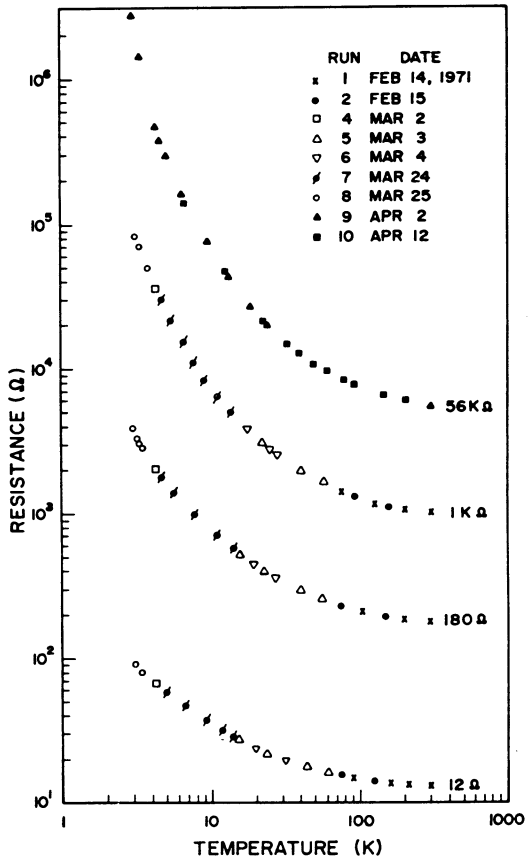

Fig. 1. Temperature calibration of four new Allen-Bradley/Ohmite resistors of different nominal values, 1/8 w.

Resistances were measured with a Leeds and Northrup dc millivolt potentiometer using a standard four terminal network. Although more precise measuring instruments were available, it was felt that the millivolt potentiometer was adequate for the purposes of the current preliminary investigation.

Results and Discussion

The broad spectrum of the results obtained is illustrated in Fig. 1, which shows the data for 12, 180, 1000, and 5600 Ω Ohmite resistors; and by Table I, which lists the measured or interpolated values of resistance at selected temperatures for all of the tested Ohmite and Allen-Bradley resistors. From Fig. 1 one can conclude that, as was also true for earlier model resistors, the general shape of the R vs. T curve is about the same for any nominal value resistor, but that the region where the slope increases more sharply shifts to higher temperatures for higher nominal values.

That the general shape of the R vs. T curves has changed in the newer model resistors is illustrated in Fig. 2. In this figure, current data for 180 and 330 Ω resistors is compared to the retabulated data of E. H. Schulte[4] (published in 1966) for a 270 Ω 1/8 watt Allen-Bradley resistor. The fact that the newer resistors exhibit a flatter slope at lower temperatures is considered an advantage for most applications because this feature means there is a wider range of temperature where a given resistor has good temperature sensitivity without having the resistance becoming prohibitively high.

TABLE I. RESISTANCE OF OHMITE AND ALLEN-BRADLEY RESISTORS AS A FUNCTION OF ABSOLUTE TEMPERATURE

R NOM \ T(K)	300	200	100	77	60	40	30	20	10	8	6	4.2
5600	5715	6020	7595	8551	9800	13100	16550	24950	67000	101500	182000	458000
3900	4026	4410	5600	6190	7050	9000	11250	16050	40000	60100	105500	264599
2200	2303	2460	3010	3364	3800	4880	6010	8400	19300	27300	45000	98371
1500	1515	1600	1950	2173	2440	3110	3770	5260	12100	16800	27100	58400
1000	1015	1067	1290	1412	1610	2115	2440	3400	7600	10300	16500	34400
1000*	1000	1038	1220	1336	1500	1860	2270	3150	6780	9600	15000	28663
1000*	969	1001	1170	1315	1440	1760	2080	2800	5640	7835	12400	26265
680	676	682	804	873	965	1200	1440	1960	4080	5600	8600	15359
470	481	488	564	628	680	830	990	1305	2540	3310	5005	9441
330	337	341	400	435	478	581	690	905	1710	2220	3280	5986
180	183	190	214	229	250	295	341	439	770	960	1320	2101
120	116	119	131	144	155	181	207	262	438	538	720	1098
82	78.9	80.1	88	93.1	99	118	133	163	261	312	410	602
82*	79.0	80.2	88.3	93.6	100	120	136	168	268	321	420	610
68	64.7	65.4	71.5	75.2	81.6	93.0	108	134	211	258	334	447
12	13.1	13.3	14.6	15.6	16.2	18.1	20.1	24.0	35.1	41.0	50.0	67.6

All resistances given in ohms
*Allen-Bradley brand; all others are Ohmite

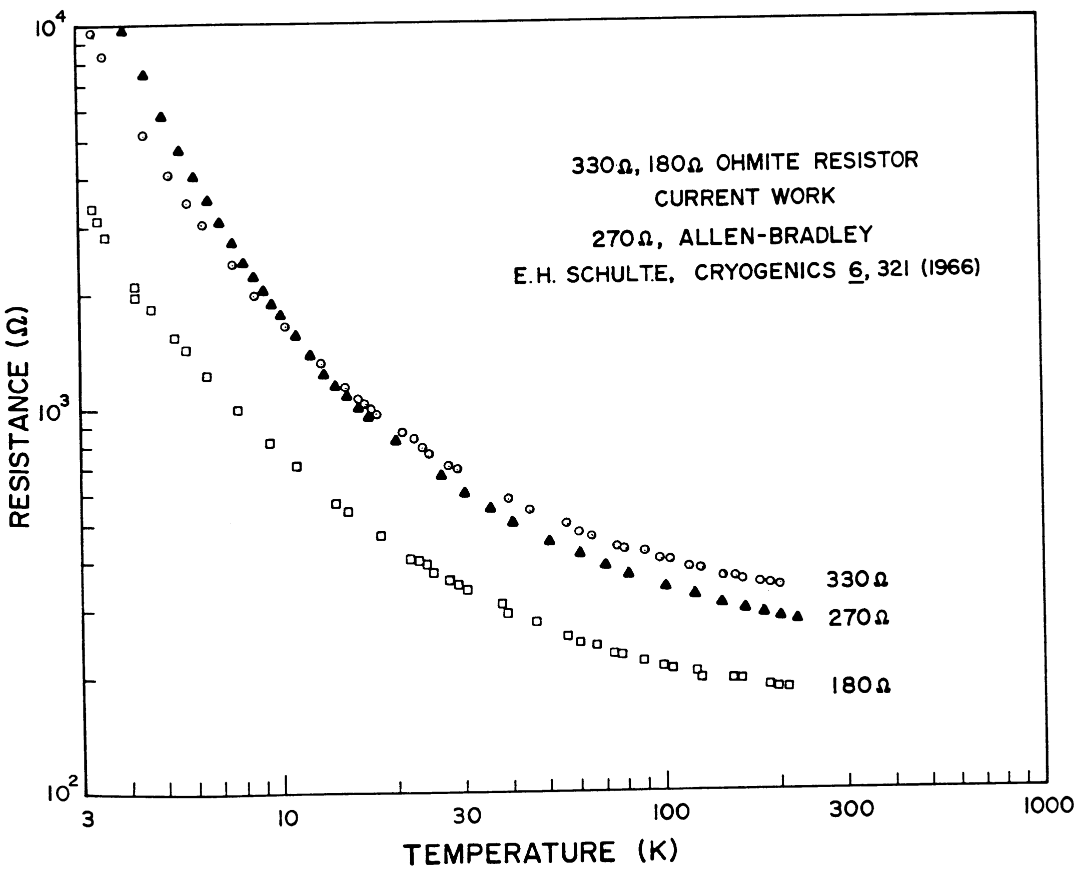

Fig. 2. Comparison of temperature calibrations for 180 and 330 Ω, 1/8 w, new Ohmite resistors and 270 Ω, old Allen-Bradley resistor.

Figure 3 presents a comparison of the data over a limited temperature range for three 1,000 Ω nominal value resistors—two Allen-Bradleys and one Ohmite. The curvature for all three is similar and there appears to be no difference in the thermometric behavior of all three in the entire temperature range, 3 to 300 K, i.e., the highest (or lowest) valued resistor at 300 K is also the highest (or lowest) valued resistor at 3 K. It is perhaps worth noting that packs of 50 resistors of either brand come encased in clear plastic containers bearing the Allen-Bradley trademark. The only physical distinction observed between the two brands was a yellow (painted) band found on the Allen-Bradley (designated) resistors. It should be noted, however, that A. C. Anderson[5] has found a slight difference in the internal mechanical construction of the two brands. Whether this represents a difference with regard to brand or to time of manufacture remains to be determined.

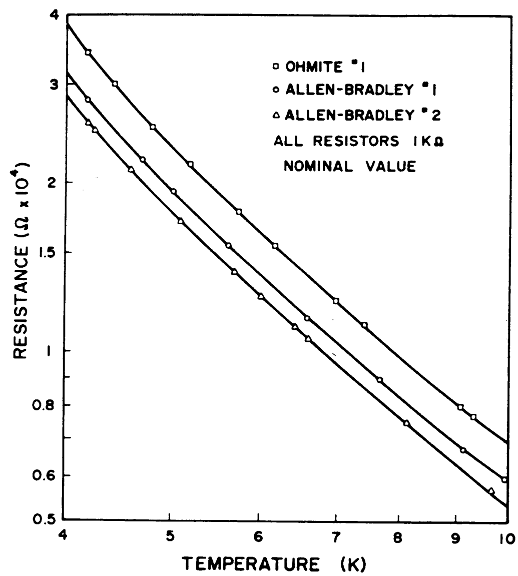

Fig. 3. Temperature calibration of three 1000 Ω, 1/8 w, resistors—two Allen-Bradley's and one Ohmite.

Reproducibility of the calibration curves from run to run appears to be within the range of experimental error, e.g., note the data points obtained on different days in Fig. 1. Another check of reproducibility involved a series of ten thermal cycles (between 4.2 and 300 K over both short and long periods of time) of the resistance of a 1000 Ω resistor at the normal boiling point of liquid ^{4}He. An apparent temperature variation of ± 0.03 K was observed and was found to be consistent with changes in the atmospheric pressure and the uncertainty of the resistance measurements.[6] The last three of the ten measurements were performed after the resistor had been resoldered into the apparatus while heat-sinked.

One peculiarity in the reproducibility of all the tested resistors should be noted. An increase in the resistance at liquid helium temperature is always observed between the first and second thermal cycles. For a 1,000 Ω resistor this was found to be a 2 percent increase. It would seem likely that this phenomenon is associated with carbon granule rearrangement due to thermal shock, but it is not clear as to why this should result in the observed behavior. Whatever the reason, it would be wise to thermally cycle a resistor one or more times before calibrating it.

Calibration

A preliminary attempt has been made to find a useful calibration equation for the data obtained. A least-squares analysis has been made for five functional forms:

$$T^{-1} = b_{-1}x^{-1} + b_0 + b_1x + b_2x^2 + b_3x^3,\ x = \log R\ , \tag{1}$$

$$T = A(\log R)/(\log R - B)^2 \tag{2}$$

$$T = A/(\log R - B)^P\ , \tag{3}$$

$$\log R + K/\log R = A + B/T\ , \tag{4}$$

$$\ln R = A + B/T + C/T^2 + D/T^3 + E/T^4 + F(\ln T)\ , \tag{5}$$

The first three of these equations have been applied recently by Balcombe, Emmerson and Potton[7] to 470 ohm, 1/2 watt Speer carbon composition resistors below 4.2 K. Equation (4) was introduced by Clement and Quinnel.[1] Equation (5) has been used for some time in the reporting laboratory to calibrate old model

TABLE II: ERROR IN CALCULATED TEMPERATURE AS A FUNCTION OF TEMPERATURE (For 5600 ohm resistor)

T/Eq.	ΔT (1)	ΔT (3)*	ΔT (4)	ΔT (5)
2.97	− .046	+ .101	+ 5.799	− .025
3.14	+ .064	+ .359	+ 1.1651	+ .040
4.20	− .010	+ .489	− 3.2054	− .001
4.50	− .019	+ .512	− 3.5299	− .064
4.85	− .0042	+ .552	− 3.6166	− .001
5.05	+ .0244	+ .589	− 3.5396	+ .062
6.10	− .0473	+ .509	− 2.8912	+ .132
6.20	− .1011	+ .453	− 2.8994	+ .084
9.40	− .439	− .175	− 0.1787	− .141
11.25	− .329	− .380	+ 1.62	− .148
12.50	− .813	−1.01	+ 1.68	− .704
13.00	+ 1.14	+ .48	+ 4.95	+ .959
18.1	+ .469	−1.04	+ 5.43	− .334
21.9	+ 2.79	+ .42	+ 7.67	+1.282
24.8	− .374	−2.71	+ 4.54	−1.858
32.3	+ 1.923	+ .09	+ 4.70	+ .821
39.8	+ .847	+ .20	+ 1.64	+2.399
50.0	− 4.76	+2.06	− 5.34	+1.323
60.0	−12.93	−2.49	−13.99	−3.872

*Eq. (3) has been modified to $T = A/(\log R/C - B/C)^p$, i.e., it contains four parameters in its modified form.

Ohmite resistors over various temperature ranges, although generally a fit to data covering only about one decade of temperature is made.

None of the above equations offers a really adequate fit. The worst fit is given by Eq. (2) having only two parameters; the best and next best fits are provided by Eq. (5) and Eq. (1), which have six and five parameters respectively. Table II present the calculated errors in temperature (up to 60 K) for all equations except Eq. (2) for a 5600 Ω nominal value resistor. The conclusion that can be drawn from these results is that none of the trial calibration equations is inherently, i.e., physically, correct and that it is probably unrealistic to expect any of these equations to provide a good fit to the data over a temperature span of two decades. Until such time as one can determine a meaningful, and hopefully simple, R vs. T relationship (if such indeed exists), it would appear that the best course is to choose a multiparameter equation, such as Eq. (5). It would appear also that more sophisticated weighting techniques should be employed in conjunction with this.

SUMMARY

The new model Allen-Bradley/Ohmite carbon composition resistors appear to have reproducible thermometric properties as reliable as those of their earlier counterparts. They exhibit a somewhat diminished temperature sensitivity toward lower temperatures which tends to make them more applicable over a wider temperature range. As yet, no simple empirical relationship has been found which adequately describes the R vs. T relationship obtained.

Acknowledgements

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References

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[3] H. Weinstock, R. A. Guenther and R. W. Schleicher, Cryo. Tech. **6**, No. 2, 7 (1970).

[4] E. H. Schulte, Cryogenics **6**, 321 (1966)

[5] A. C. Anderson, *Temperature, Its Measurement and Control in Science and Industry* (Instrument Society of America, Pittsburgh, 1972) Vol. 4, Part 2, p. 773.

[6] Higher precision measurements have been taken subsequent to the oral presentation of this paper using a Leeds and Northrup K-3 microvolt potentiometer. With this instrument, only an instrumental uncertainty equivalent to 0.013 K at 4.2 K is introduced for the 1,000 Ω resistor, although actual differences on cycling–about 25 times with leads resoldered 5 times–showed less than the equivalent of a 0.0015 K drift after 9 hours with stability established by that time.

[7] R. J. Balcombe, D. J. Emerson, and R. J. Potton, J. Phys. E: Sci. Instr. 3, 43 (1970)