RECENT INVESTIGATIONS INTO THE TEMPERATURE AND PRESSURE CHARACTERISTICS OF PRECISION 1Ω RESISTORS AT THE NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY

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Abstract

Recent modifications to the precision 1 Ω resistor current comparator systems at the National Institute of Standards and Technology (NIST) allow for improved determination of the temperature and pressure coefficients of precision 1 Ω resistors. This capability allows NIST to better characterize the Thomas resistors used for inter-laboratory comparisons, and will be employed to evaluate the reported specifications of several commercially available precision 1 Ω resistors.

Overview and Background

Shortly after Dr. James L. Thomas first constructed hermetically sealed 1 Ω resistors in the 1930's, it was observed that the Thomas type resistor [1,2,3,4] has both a temperature and a pressure coefficient. This temperature dependence is due to the Manganin wire used, and the pressure dependence is due to the strain transferred through the thin inner wall of the sealed resistor shell. At NIST these coefficients were determined for the working standards and control resistors used in the Thomas type measuring system so that corrections due to temperature and pressure variations could be applied.

Since then, two types of new, precision 1 Ω resistors constructed using Evanohm wire have become available. These resistors have been reported to have smaller temperature coefficients than those of the Thomas type resistor. The Australian National Measurement Laboratory (NML, now part of the National Measurement Institute) [5,6] reports that by using the Evanohm‡ alloy, and a specialized heat treatment program, precision 1 Ω resistors can be fabricated with a resistance close to nominal value and with a temperature coefficient below 0.02 (μΩ/Ω)/°C. Through a new annealing process of the resistance element and changes in the structural mounting design, Measurements International Limited‡ (MIL) has also developed and marketed a precision 1 Ω resistor with a temperature coefficient below 0.05 (μΩ/Ω)/°C. This is a significant improvement over the Thomas type resistors which typically have temperature coefficients from 1 to 3 (μΩ/Ω)/°C.

The Physikalisch-Technische Bundesanstalt (PTB) has reported [7] that some Thomas type resistors exhibit a non-reversible shift in their values of up to several parts in 10^7 when the resistors are exposed to temperatures that differ from the laboratory's usual maintenance temperature (20 °C). The value at 20 °C exhibited a permanent decrease (or increase) when removed from the oil bath and cooled (or warmed). These effects were noticeable even when the temperature treatment was an increase in temperature from 20 °C to 22 °C, 24 °C, or 26 °C for a few hours.

Temperature and Pressure Components

An auxiliary oil bath was incorporated into the first of two Thomas 1 Ω measurement systems. The standards, controls and customer resistors are compared at 25 °C, while up to three additional 1 Ω standard resistors can be calibrated at variable temperatures. The auxiliary oil bath has temperature stability better than one millidegree and a range of 20 °C to 30 °C

A second system incorporates a pressure chamber consistinf of a rectangular aluminum box partially filled with mineral oil, and fitted with pressure ports. This box also can hold three Thomas type resistors and is submerged completely in an oil bath maintained at 25 °C.

Resistor Temperature Measurements

So far about twelve Thomas type re-sistors were tested at 20 °C, 23 °C, 25 °C and 26 °C. Initially, each resistor was measured in the main oil bath at 25 °C in order to establish a base value and drift for each resistor. The resistors were then transferred to the auxiliary oil bath and measured at each temperature for seven to ten days. After each test at a particular temperature the resistor was returned to the main oil bath and measured at 25 °C to ensure that no permanent shift in the resistor value had occurred.

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‡ Certain commercial equipment, instruments, or materials are identified in this paper to specify the experimental procedure adequately. Such identification is not intended to imply recommendation or endorsement by the National Institute of Standards and Technology, nor is it intended to imply that the materials or equipment identified are necessarily the best available for the purpose.

At NIST the temperature coefficients are usually designated by α for the first order effect and β for the second order coefficient (see Fig. 1). The Thomas resistors that were tested all had β coefficients in the range of (−0.533 to −0.547) (μΩ/Ω)/(°C)^2. Most had α coefficients in the range of (2.05 to 2.65) (μΩ/Ω)/°C with two falling outside this range and having α coefficients of 3.05 (μΩ/Ω)/°C and 4.98 (μΩ/Ω)/°C.

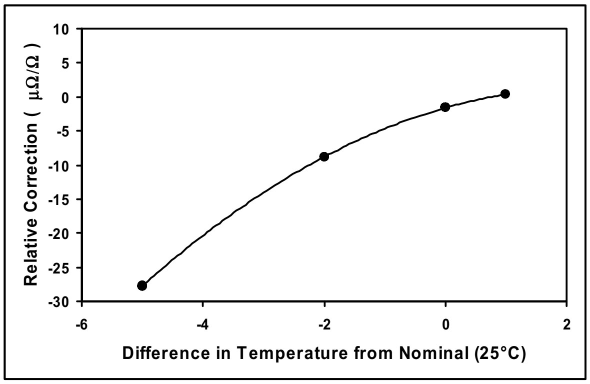

Fig. 1. Typical response of a Thomas 1Ω resistor at temperatures from 20 °C to 26 °C.

There usually was some temporary drift in the value of the resistor, but almost all returned to the trend line indicating the normal drift in the resistor value (Fig. 2).

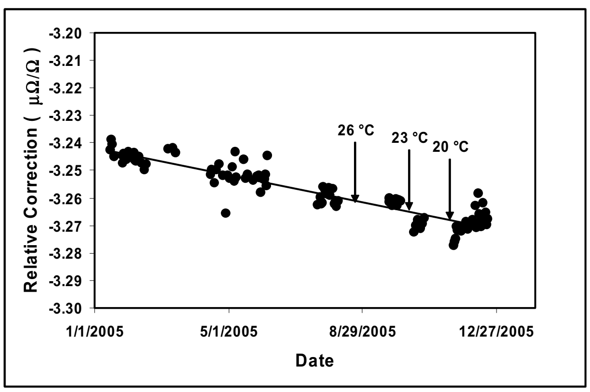

Fig. 2. Value of a test resistor as measured in the main oil bath at 25 °C. The arrows indicate when the resistor was tested at 26 °C, 23 °C, and 20 °C.

Resistor Pressure Measurements

The value of the resistor was measured at barometric pressures approximately (−20 to +10) kPa from the standard pressure of 101.325 kPa. The resistors were kept at each pressure value for 10 to 14 days. The resistor values changed nearly linearly with pressure and our measured values for the pressure coefficient varied from (0.0027 to 0.0238) (μΩ/Ω)/kPa. Again, once the tests were completed the resistor was returned to the main oil bath and measured at 25 °C to ensure that there had been no permanent shift in the value.

Future Efforts

Several Thomas 1Ω resistors have undergone a series of temperature and pressure test to determine their temperature and pressure coefficients. Tests on a total of fifteen Thomas type resistors are continuing at NIST. Some will be tested over a larger temperature range. Further, NIST will test five additional precision 1 Ω resistors from NML and MIL and compare their temperature and pressure characteristics to those of the Thomas type of resistor.

Beginning in 2006, NIST will pilot an international comparison in which two well characterized Thomas 1 Ω resistors will be sent to various national laboratories in the western hemisphere. For the best possible international comparison both the thermal and the pressure characteristics of these resistors have been re-measured so that significant effects of temperature and pressure variations on the test resistors can be corrected. Two resistors with the best characteristics have been chosen to participate in the comparison.

Interest in determining the pressure coefficients of precision 1Ω resistors goes beyond the selection of resistors for standards or comparisons. Permanent shifts in resistor values with changes in pressure have been measured at NIST. Further, other laboratories have reported to NIST long lasting hysteretic pressure effects.

References

[1] J. L. Thomas, "Stability of Double-Walled Manganin Resistors," J. Res. Natl. Bur. Stand., Vol. 36, pp. 107-110, January 1946.

[2] F. Delahaye, "DC and AC Techniques for Resistance and Impedance Measurements," Metrologia, Vol. 29, pp. 81-93, 1992.

[3] R. F. Dziuba, "Pressure Dependencies of Standard Resistors," Conf. Proc. NCSL Workshop & Symposium, pp. 363-369, 1993.

[4] H. Karlsson and T. Sørsdal, "Pressure Coefficients of 1 Ω Thomas-type Resistance Standards," Metrologia, Vol. 32, pp. 389-391, 1995/96.

[5] B. J. Pritchard and R. C. Grime, "Fabrication of Reference Standard 1 Ohm Resistors from Evanohm Alloy," CPEM'90 Digest, pp. 290-291, June 1990.

[6] B. J. Pritchard and G. W. Small, "Temperature Coefficient Variations in Heat Treated Evanohm and Their Effect on the Transient Behavoir of the NML 1Ω Resistors," IEEE Trans. Instrum. Meas, Vol. 42, No. 2, pp. 557-561, April 1993.

[7] H. Leontiew and P. Warnecke, "Non-Reversable Behavoir of Precision Standard Resistors Due to Temporary Changes in the Maintenance Temperature," PTB-Mitteilungen, Vol. 102, pp. 289-290, April 1992.