Pressure and Temperature coefficients of commercial 1 Ω Standard resistors

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Abstract: Changes in ambient pressure can effect change in the resistivity of some alloys used in the manufacture of resistors. Increasingly, inter-laboratory resistance comparisons at both national and international levels include laboratories with an ambient pressure significantly different from normal atmospheric pressure. Recent work [1] has also suggested that exposure to small temperature changes such as those experienced during transport between laboratories can have an hysteric effect on the measured value of a resistor. We have investigated the effect of pressure and temperature cycles on a number of commercially available 1Ω resistors. We will present our findings in detail, with particular reference to the implications for high precision inter-laboratory comparisons.

1. Introduction

At any time the measured value of a standard resistor will be affected by a number of parameters. Some of these are listed in Table 1. The recent rapid growth in the numbers of inter-laboratory comparisons coupled with the increasing availability of accurate and precise instrumentation has placed ever tighter limits on the performance of such standard resistors. Besides the measurement conditions in the laboratory it has become increasingly important to consider possible effects of factors such as the pressures and temperatures to which standards are exposed during transport between laboratories. Whilst traveling,artifacts may be exposed to temperatures varying from -40°C to 60°C and pressures that range from 457 to 760 mmHg. This may lead to temporary or to permanent change in the resistance values. In addition of course resistors also

Shelf Factors	Construction factors	Measurement factors
Ageing	Material	Time
Oxidation	Geometry	Temperature
Temperature	Adjustment	Pressure
	Annealing	Humidity
	Ageing	Loading
		Mishandling
		Transport effects

Table 1: Some factors affecting the measured value of standard resistors.

age, in differing ways. with time. In this paper we will present and discuss data illustrating the effects of changes in time, temperature and pressure on a set of typical commercial 1 Ω resistors.

2. Experimental details

We selected seven types and makes of 1 Ω resistors from various manufacturers (see Table 2) and investigated their behaviors when exposed to a range of pressures and temperatures. The pressure measurements were made at constant temperature, and the temperature measurements at constant pressure. During a set of measurements we monitored ambient pressure, temperature and humidity.

The measurements were made by comparing each resistor in turn with a reference1 Ω resistor. Parameters for the resistors under test were changed between measurements, but not during measurements. Following a change of either pressure or temperature a minimum wait of four hours was imposed before measuring, to allow any induced changes to stabilize.

Make	Model
NML	"Thomas" type
Guildline	9330
Tinsley	3504
MIL	9210A
Fluke	742-A
L&N (rosa)	-
L&N (Thomas)	4210

Table 2: Makes and models of resistors tested.

All resistance measurements were made with a Measurements International 6010A dc current-comparator bridge, the various resistors being connected in turn under computer control via a Measurements International 4010A scanner. Currents of 50 uA were used for all pairs. Considerable care was taken with cable shielding connections and with thermal lagging of the rear panels of the scanner and the bridge, to minimize measurement noise. Typically this was of the order of ± 0.01 ppm, after ten minutes of measuring a particular resistor pair. Since we were only interested in the relative change of the resistors we did not reverse the bridge connections: the bridge error was assumed to be constant for all measurements.

2.1 Pressure Measurements.

The resistors to be tested were placed in a pressure vessel (Figure 1) which in turn was placed in an air bath maintained at 23°C ± 0.1°C. The vessel was Teflon coated on the inside and the seven DUT were separated into two batches to accommodate the size of the pressure vessel. Temperature and pressure probes were sealed through the lid of the vessel to monitor the pressure and temperature inside (Figure 1). During the pressure measurements, the standard against which the devices under test (DUT) were measured was maintained in oil at a temperature of 25 °C ± 0.05°C and at normal atmospheric pressure.

Beginning at atmospheric pressure we first increased the pressure, in steps of about 48 mm Hg, to the maximum value, stepped back down to the minimum, then returned to the starting value. A diaphragm pump/compressor was used to adjust the pressure as required, then the vessel was sealed and allowed to stabilize at it's new set pressure before measurements were made.

Figure 1. Details of the pressure vessel.

2.2 Temperature Measurements.

Six of the 1Ω resistors under test were placed in a Guildline 5010 oil bath. The Fluke 742A resistor was placed in a VWR 2005 air bath, which has a stability of ± 0.1°C. The temperature was cycled, in steps of four degrees, from 23°C up to 31°C, back down to 15°C then back to 23°C. During this time, the reference was maintained in air at 25°C ± 0.1°C. The temperatures of the oil bath and the two air baths were monitored independently.

2.3 Time Measurements.

Some of the 1 Ω resistors investigated are relatively new, and we have not yet had time to investigate fully their ageing characteristics. However we believe the data we present below to be representative of the typical ageing behaviour of resistors of the types under discussion. The data presented have all been collected during the past ten years, i.e. since we implemented a quantised Hall resistance as our primary standard of resistance, and all the data are traceable to this primary standard, which is thought to be stable with time.

3. Results and Discussion

3.1 Changes with time.

Figure 2a illustrates typical time-dependent behaviour of a Tinsley 5685A resistor maintained under stable conditions. This particular resistor has been held at steady temperature, within ± 0.05 °C, since it was put into an air bath three years ago. It increases in value slowly with time, but the rate of change appears to be leveling off with time. Experience with other resistors of the same type suggests that ultimately we may achieve a stability of around 0.01 ppm per year.

In 2b we show data for a Guildline 9330, which has been in a standard cell enclosure, essentially at fixed temperature for fifteen years now. It continues to behave in a very predictable way, showing a regular linear increase of value with time. Unlike the example in 2a, the Guildline 9330, though predictable, shows no sign of "plateauing."

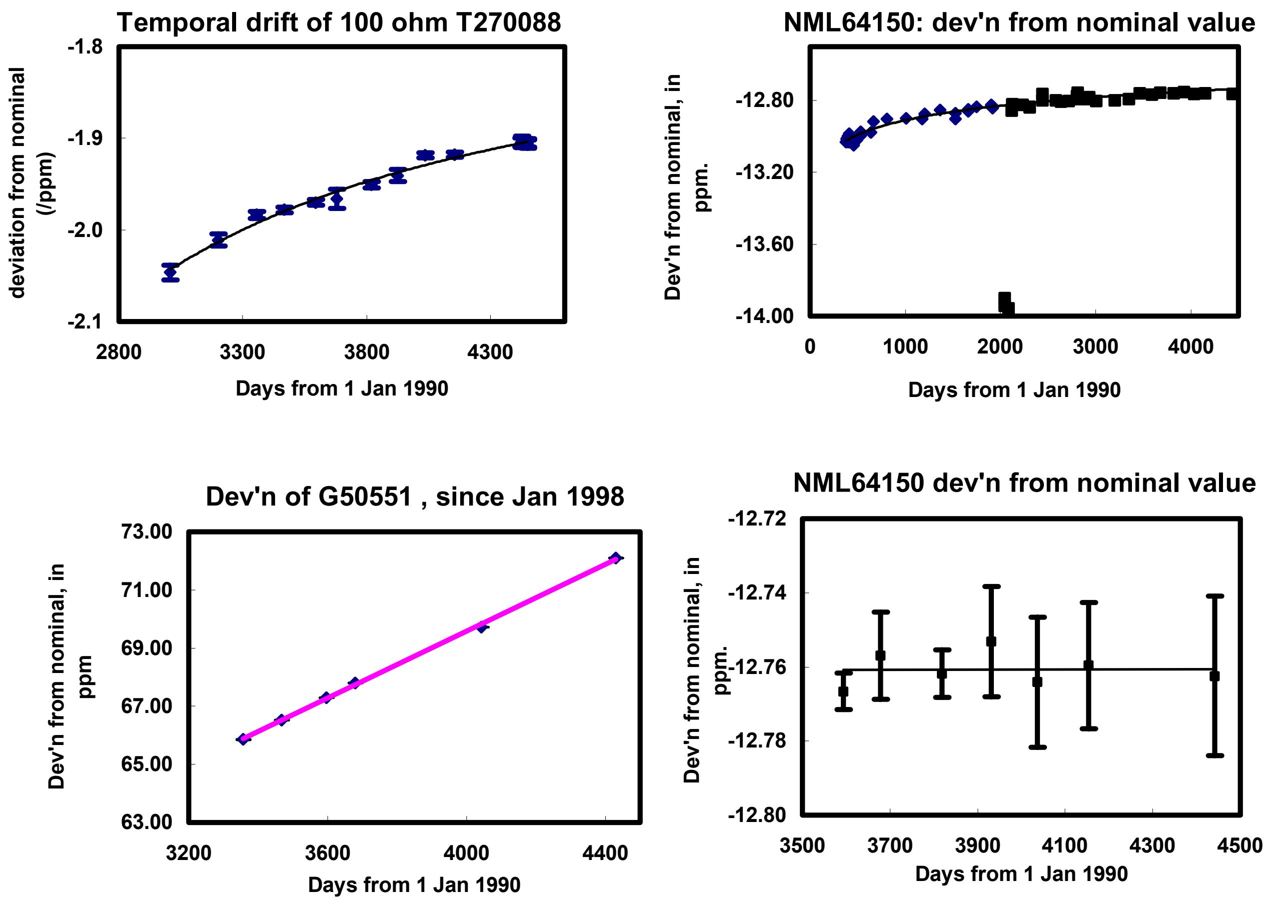

Figure 2. (a, b, c, d, anti-clockwise from the top left). Time dependence of values of resistors, measured over several years.

The data in Figure 2c are for a NML CSIRO Thomas type 1 ohm resistor. Measured over the last three years this resistor is essentially unchanging with time, although unlike with the previous two examples no effort is made to maintain this resistor under especially stable conditions. A fit to the slope gives a rate of change of 0.3 pΩ per day, or 1 ppm in 10 000 years! Over a longer time period we see (Figure 2d) the same sort of behaviour as tat of the Tinsley 5685A of Figure 2a – the stability is arrived at gradually over time. However one should also note the abrupt change of value for this NML resistor that occurred as a step change at around the 2000 day point. The origin of this step change is not understood, but its importance is that it shows that even with an apparently stable and well-behaved resistor one has to monitor the value on a regular basis.

Both the long term drift behaviour and the fact that even ultra stable resistors can be subject to step changes in value emphasise the need for both before and after measurements whenever resistors are used as traveling artefacts in an intercomparison.

3.2 Changes with pressure.

The pressure measurements show essentially three different behaviors, illustrated in figure3. The two resistors in Figure 3a show an oscillatory behavior with changing pressure over a small (~ 0.1 ppm) range, returning to about the same value when returned to the starting pressure. This suggests that although pressure changes during travel may temporarily affect their value, returning to the starting pressure will essentially reset the value.

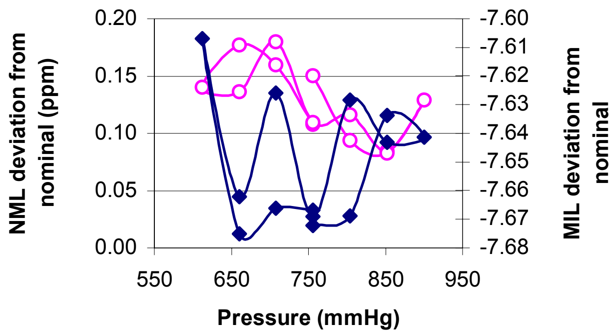

Figure 3b shows a similar behaviour for the Guildline 9330, except that imposed on the small oscillatory change there is an increase in value with increasing pressure. Also, for the pressure range used the span of resistance variation is more than three times that of the least pressure sensitive resistor I Figure 3a – the NML resistor.

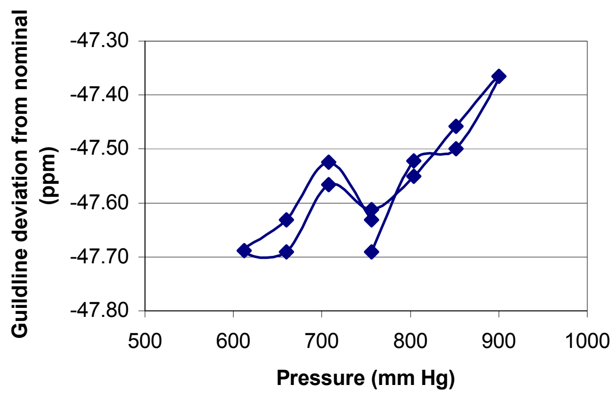

Figure 3b. Pressure dependence of a Guildline 9330 1 Ω resistor.

Figure 3c shows the behaviour of the Leeds and Northrup Thomas-type1 Ω, which is used by many laboratories as a standard. This resistor is the most sensitive of all those tested to changes in pressure, although it like the others returns close to the starting point after a pressure change cycle. However the closeness of return does seem to be somewhat time dependent. We are still investigating the relaxation rate for this type of resistor, and hope to report more details at the conference. In the meantime it should be noted that for this type of resistor there can be a change in resistance of more than 1 ppm with a pressure change of only about 50 mmHg. This could be of some consequence for comparisons involving laboratories at different heights above sea level.

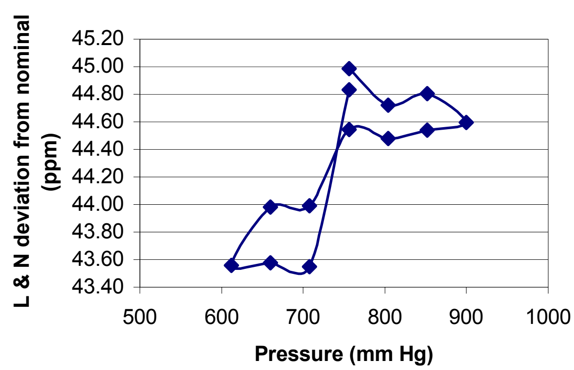

Figure 3c. Pressure dependence of a Leeds & Northrup Thomas-type 1 Ω resistor.

3.3 Changes with temperature.

Figures 4 (a) – (c) show typical behaviour of the 1 Ω resistors with changing temperature. With the exception of the NML Thomas type which has an exceptionally flat characteristic over this temperature range all show some version or other of the behaviour shown in 4a, for the Fluke resistor. Around room temperature the value is almost flat with temperature over a small range of temperature, curving away as the difference from room temperature increases. The value at which the curve flattens depends on the resistor and the type (since it is essentially a material dependent property). For the case of the Guildline and the L&N resistors in fact a flat section for the resistance temperature curve is not attained, for the range of temperatures investigated.

Whilst it is clearly important to accurately specify and set measuring temperature for these resistors, and for the L&N type in particular, only the Fluke 742A and the NML resistor show an indication of appreciable hysteresis in the resistance temperature curve. Previous measurements of the NML resistor showed no indication of hysteresis, although in [1] hysteretic behaviour was reported for many resistors when cycled over a larger temperature range than was used for the work reported here.

We will investigate these hysteretic behaviours further – it may be that a longer relaxation time is required for these resistors after a step temperature change – and hope to have more data available in time for the conference.

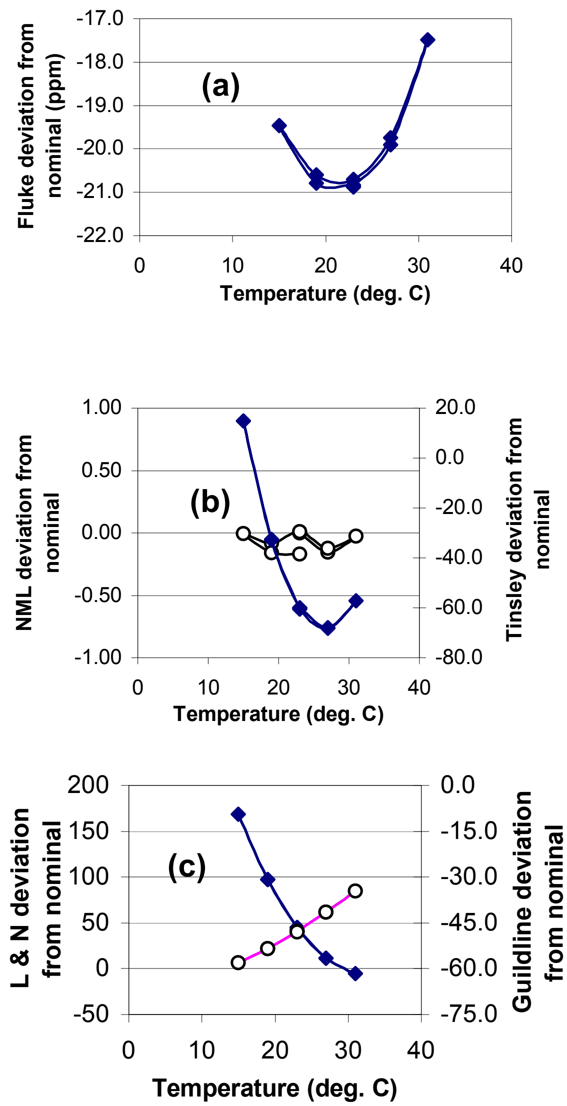

Figure 4. Deviation of resistance values with time. All deviations are in ppm. (a) is a Fluke 742A, in air. In (b) the open circles are an NML Thomas type, the solids a Tinsley type 3504. And in (c) the open circles are a Guildline 9330, the solids a Leeds and Northrup Thomas type.

Conclusion

We have commenced a detailed investigation of the effects of temperature and pressure changes on the values of one ohm standard resistors. Some of the preliminary findings are reported here.

Perhaps the most important, from the point of view of laboratory inter-comparison is that the Leeds and Northrup Thomas type 1 Ω standard resistor is relatively pressure dependent, small changes in pressure of a few tens of millimeters of mercury producing as much a s1 ppm change in value.

We do not find evidence for hysteretic behaviour, as previously reported in [1], for most type of resistor studied, for the temperature range considered here for. We will be extending the temperature range studied in the future, but possibly not in time for the conference in August.

References

1. P. Warnecke et al, “Hysteric and reversible anomalies of resistance alloys” CPEM’98 Conference Digest, pp 518-519.