Producing the Highest Accuracy from SPRTs

The handling and use of an SPRT are as important in achieving a high level of accuracy as the design and performance of the SPRT itself. Several types of errors can corrupt SPRT measurements. This article will provide an overview of sources of error and ways to improve SPRT accuracy.

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The Standard Platinum Resistance Thermometer (SPRT) is the most accurate thermometer in the extended temperature range from –259° to 962°C. The uncertainty of an SPRT can be as low as a few tenths of a millikelvin (mK).

More and more calibration specialists are using SPRTs as reference standards to calibrate other types of thermometers or to achieve a high level of accuracy. However, the handling and use of an SPRT is as important in achieving a high level of accuracy as the design and performance of the SPRT itself. Several types of errors can corrupt SPRT measurements.

Sometimes absolute resistance is used to calculate temperature instead of the resistance ratio. When absolute resistance is substituted for the resistance ratio, errors of more than 10 mK at 660°C are common. In addition, even when the correct measurement and calculations are made, the resistance of the SPRT at the triple-point-of-water (TPW) should be determined immediately after a high-accuracy measurement is made with the thermometer.

The triple-point-of-water measurement is often overlooked but vital to accuracy. The relationship of the triple-point-of-water measurement to SPRT accuracy is explained with a few key points.

TPW AND ACCURACY

Stability in SPRTs is the first issue. In general, they have excellent stability; however, a small drift in resistance might happen occasionally, especially after transportation, thermal cycling, or some other situation such as accidental rough handling. A change as low as 1 ppm in resistance at about 660°C (the freezing point of aluminum) is equivalent to a change of 1.1 mK in temperature. The stability required of a high-quality standard resistor is about 1 ppm. The working and environmental conditions normally associated with standard resistors is much better than the conditions usually found when working with an SPRT. So a few ppm of stability might be the best we can expect for most SPRTs.

The ratio of two resistances of an SPRT based on two temperatures is much more stable than the stability expected when an absolute resistance at a single fixed temperature is used. For example, using only the freezing point of silver as a reference point over a six-year time frame, an SPRT might show a change of 5 ppm in its resistance[1]. This is equivalent to a change of 7.5 mK in temperature. On the other hand, the change in the resistance ratio, [W(961.78°C=R(961.78°C)/(R(0.01°C)], is within 1 ppm (a change of 2mK in temperature) across the same six-year period. This is why the resistance ratio W(t) has been

TABLE 1 — THE EQUIVALENT TEMPERATURE ERROR CAUSED BY AN ERROR IN RESISTANCE MEASUREMENT

Temperature	Temperature error caused by an error of 1 ppm in resistance measurement	Resistance error equivalent to an error of 1 mK in temperature
(°C)	(mK)	(ppm)
−200	0.04	25.4
−100	0.14	6.9
0.01	0.25	4.0
232	0.51	2.0
420	0.74	1.4
660	1.1	0.9
962	1.5	0.7

specified by the International Temperature Scales instead of the absolute resistance R(t) since 1960.

The best method for accomplishing this ratio is to use the triple-point-of-water as the second temperature because of its excellent stability and simplicity. It has been specified as a reference point for SPRTs since 1960[2]. Thus, the highest SPRT accuracy is achieved when the resistance of an SPRT at the triple-point-of-water (R_{tp}) is determined immediately after a measurement at any other temperature.

Use of the ratio method also reduces system error introduced by any electronic readout. This reduction in system error is important because as little as 0.7 ppm of error in resistance will cause an error of 1 mK in temperature (see Table 1).

FREQUENCY OF R_{tp} MEASUREMENT

When accuracy requirements don't extend to the highest levels, R_{tp} may need measured only once a day, every few days, or at some other suitable interval. How frequently R_{tp} needs measured depends on several factors such as acceptable uncertainty, the stability of the SPRT, the measuring temperature range, and the working conditions. If the required uncertainty is 1 mK or so, R_{tp} measurement should follow each R_t measurement. If accuracy requirements are 20 mK or more in a temperature range lower than 420°C and the SPRT used is quite stable, the R_{tp} might be measured once a week. The stability over time of each SPRT must be measured even when using SPRTs manufactured in the same lot from the same supplier.

When temperature measurements are higher than 800°C, it is better to measure the R_{tp} as soon as the SPRT cools down to room temperature. Whenever possible, an SPRT should cool down to at least 500°C with a low cooling rate (about 100°C per hour). Otherwise the SPRT should be annealed before making a measurement at the triple-point-of-water.

A suitable annealing procedure is a two-hour anneal at 700°C, at the end of which the SPRT is allowed to cool to 450°C over a period of about two and a half hours. After this initial cooling period the SPRT can cool quickly to room temperature. Fast cooling from high temperatures above 500°C may cause significant increases in R_{tp} because of the quenching-in effect on lattice defects found in platinum wire. This increase of R_{tp} could be as large as 30 mK.

CAN THE R_{tp} GIVEN IN THE NIST CALIBRATION REPORT BE USED TO CALCULATE THE RATIO?

Some calibration specialists may feel the R_{tp} measured by NIST is more accurate than that measured in their own lab, so they prefer to use the value for R_{tp} given in the *NIST Calibration Report* to calculate the resistance ratio in the interpolation equation. While it's true the accuracy of

NIST's measurements are generally much better than those done in other labs, the R_{tp} of the SPRT may have changed during transportation and so should be measured again in your own lab. Furthermore, to reduce system error, the R_{tp} should be measured using the same instrument in the same time frame as the R_t, and with the readout included in the measuring procedure. It is important to always use the same readout instrument to measure both R_t and R_{tp}.

AVOIDING MECHANICAL STRAIN AND THE ANNEALING PROCEDURE

An SPRT is a delicate instrument. Shock, vibration, or any other form of acceleration may cause strains that change its temperature-resistance characteristics. Even a light tap, which can easily happen when an SPRT is put into or taken out of a furnace or a triple-point-of-water cell, may cause a change in R_{tp} as high as 1 mK. Careless handling of an SPRT over a long period of time, such as a year, has resulted in R_{tp} increases equivalent to 0.1°C.

An annealing at 660°C for an hour will relieve most of the strains caused by minor shocks and nearly restore the R_{tp} to its original value. If the maximum temperature limit for an SPRT is lower than 660°C, it should be annealed at its maximum temperature. Such an annealing procedure is always advisable after any type of transportation.

The annealing furnace should be very clean and free of metals, such as copper, iron and nickel. SPRTs are contaminated when they are annealed in furnaces containing a nickel block, even when SPRTs are separated from the nickel block by quartz sheaths[3]. Well designed, clean annealing furnaces are important to quality measurements with SPRTs.

CONCLUSIONS

SPRTs are among the finest temperature measuring devices known. However, high accuracy comes at a price and not just in terms of money. Patience, care and proper procedures are major factors in producing high-quality measurements.

Support instruments such as triple-point-of-water cells are inexpensive and simple to use. Annealing is a well understood process. Uncompromised measurements are possible in almost every laboratory situation. □

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