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# A COMPARISON BETWEEN A RESISTANCE BRIDGE AND AN INTEGRATED-CIRCUIT RESISTANCE THERMOMETER READOUT USED FOR SPRT CALIBRATION

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**Abstract:** Specially designed bridges are used for standard platinum resistance thermometer (SPRT) calibration to achieve lowest uncertainty. Such bridges are expensive and their measuring speeds are slow. A new type of instrument reported a few years ago was compared against the bridge to see if it is possible to use the new instrument instead of the bridge for SPRT calibration in some cases. Four SPRTs were calibrated at the triple point of water and the freezing points of tin and zinc using a Model 6010T Bridge and the new instrument (Model 1590) simultaneously. At these calibration points the maximum differences between the two instruments were within 0.4 mK at the tin point, and within 0.7 mK at the zinc point. The maximum difference in resistance ratio W(t) at these points was within 0.9 ppm of the readings. The differences over the entire range from 0°C to 419.527°C were calculated for the four SPRTs. The maximum differences were within 0.1 mK close to 0°C, within 0.5 mK at 300°C and within 0.7 mK at 420°C. The comparison results show the new instrument can be used for SPRT calibration to achieve an expanded uncertainty (k=2) as low as 1.5 mK.

## 1. Introduction

Specially designed bridges are used for SPRT calibration. Many of them can achieve an expanded uncertainty of 0.1 ppm or lower for the resistance measurements. Their contributions to the total SPRT calibration uncertainty are 0.025 mK or lower at the triple point of water (TPW), and 0.11 mK or lower at the freezing point of aluminum (FPAl, 660.323°C), which are usually much less than one third of the total SPRT calibration uncertainty. But such bridges are expensive and their measuring speeds are slow. A new type of instrument was reported a few years ago [1] which is much easier to use and inexpensive compared to bridges, and which is capable of achieving an expanded uncertainty (k=2) of 1 ppm of the reading for the SPRT resistance measurements in certain ranges and conditions. If the new instrument is used for SPRT calibration, its contributions to the total SPRT calibration uncertainty might be 0.25 mK at the TPW, 0.51 mK at the freezing point of tin (FPSn), 0.74 mK at the freezing point of zinc (FPZn), and 1.0 mK at the FPAl according to our calculation. Such uncertainty level should be good enough for many SPRT calibrations. But almost all SPRT calibrations only use bridges up to now. In order to verify our calculation and to check whether the new instrument is good enough for SPRT calibration, four SPRTs were calibrated at the TPW, FPSn, and FPZn using a Model 6010T Bridge and the new instrument (Model 1590) simultaneously. The comparison results between the bridge and the new instrument for SPRT calibration are reported here.

## 2. Apparatus and Operation

Three fixed points (TPW, FPSn, and FPZn) were used in the comparison. TPW cells [2] were maintained in a bath at a temperature of about 0.007°C. The ice mantle frozen in a TPW cell will last for more than two months in this way. The freezing points of tin and zinc used were the working standards in the Hart Cal Lab for routine SPRT calibration. The expanded uncertainties (k=2) of the realizations were within 0.1 mK at the TPW, within 0.75 mK at the FPSn, and within 0.94 mK at the FPZn. Four 25.5-ohm SPRTs [3] were used in the comparison, and their stabilities at the TPW were better than 1 mK annually. The Model 6010T Bridge used in the comparison has an accuracy less than 0.05 ppm according to the manufacturer's user manual [4]. The Model 1590 new instrument has an expanded uncertainty (k=2) of 1 ppm of the reading for the resistance measurement in the range from 25 ohms to 400 ohms when a 100-ohm reference resistance is used according to its user manual [5]. A 10-ohm reference resistance is used with Model 6010T and a 100-ohm reference resistance is used with Model 1590. Both reference resistances are maintained in baths at a temperature of 25°C ± 0.01°C.

The realization of the freezing points of tin and zinc followed the standard procedures for SPRT calibration in the Hart Cal Lab. When an SPRT reached thermal equilibrium with the pure metal in the cell during a freezing plateau, the resistance of the SPRT was measured by the 6010T Bridge and Model 1590 successively. Each measurement was operated at a current of 1 mA, then 1.414 mA, and finally 1 mA again. The resistance corresponding to the zero power can be calculated from the measurements. The operations and data collections of both instruments were fully automated by connecting them to PC computers. It took an average over a period of four minutes at each current for Model 1590 in order to achieve an expanded uncertainty (k=2) bellow 1 ppm. Similar measurements were taken at the TPW and the resistance ratios $W(t) = R(t)/R_{tp}$ were then calculated. The resistance ratios rather than the absolute resistances were compared to compensate for the use of the two different reference resistances (the 10-ohm reference resistance for the bridge and the 100-ohm reference resistance for the Model 1590).

## 3. Comparison Results at the Fixed Points

The comparison results at the FPSn are summarized in Table 1, and those at the FPZn, in Table 2. The maximum difference in the resistance ratios W(Sn) of the four SPRTs between two instruments was 0.0000013 (0.69 ppm), equivalent to a temperature difference of 0.35 mK. The maximum difference of the four SPRTs at the FPZn was a little larger (0.0000023), but still within 1 ppm (0.89 ppm, equivalent to 0.62 mK). The comparison results proved experimentally that the estimated expanded uncertainty of 1 ppm (k=2) for Model 1590 is appropriate.

Table 1. Comparison results between Model 6010T bridge and Model 1590 at the FPSn

| SPRT S/N: | | S01 | S02 | 4011 | 4054 |
|---|---|---|---|---|---|
| R(Sn) | Model 1590 | 48.2581196 | 48.3059858 | 48.3341137 | 48.3833136 |
| | Model 6010T | 48.2581573 | 48.3060073 | 48.3341525 | 48.3833374 |
| | $\Delta$R(Sn) | -0.0000377 | -0.0000215 | -0.0000387 | -0.0000239 |
| | ppm | -0.78 | -0.45 | -0.80 | -0.49 |
| Rtp | Model 1590 | 25.4974917 | 25.5217462 | 25.5373374 | 25.5630711 |
| | Model 6010T | 25.4974952 | 25.5217399 | 25.5373643 | 25.5630828 |
| | $\Delta$Rtp | -0.0000035 | 0.0000063 | -0.0000269 | -0.0000118 |
| | ppm | -0.14 | 0.25 | -1.05 | -0.46 |
| W(Sn) | Model 1590 | 1.89266146 | 1.89273827 | 1.89268415 | 1.89270348 |
| | Model 6010T | 1.89266267 | 1.89273958 | 1.89268367 | 1.89270354 |
| | $\Delta$W(Sn) | -0.00000122 | -0.00000131 | 0.00000048 | -0.00000006 |
| | ppm | -0.64 | -0.69 | 0.25 | -0.03 |
| | $\Delta$t (mK) | -0.327 | -0.353 | 0.128 | -0.017 |

Table 2. Comparison results between Model 6010T bridge and Model 1590 at the FPZn

| SPRT S/N: | | S01 | S02 | 4011 | 4054 |
|---|---|---|---|---|---|
| R(Zn) | Model 1590 | 65.4946639 | 65.5602371 | 65.5977662 | 65.6646649 |
| | Model 6010T | 65.4947046 | 65.5602638 | 65.5977859 | 65.6647134 |
| | $\Delta$R(Zn) | -0.0000408 | -0.0000267 | -0.0000197 | -0.0000485 |
| | ppm | -0.62 | -0.41 | -0.30 | -0.74 |
| Rtp | Model 1590 | 25.4974864 | 25.5216794 | 25.5373246 | 25.5630341 |
| | Model 6010T | 25.4975107 | 25.5216670 | 25.5373260 | 25.5630411 |
| | $\Delta$Rtp | -0.0000243 | 0.0000124 | -0.0000014 | -0.0000070 |
| | ppm | -0.95 | 0.49 | -0.05 | -0.27 |
| W(Zn) | Model 1590 | 2.56867139 | 2.56880576 | 2.56870159 | 2.56873517 |
| | Model 6010T | 2.56867054 | 2.56880806 | 2.56870222 | 2.56873637 |
| | $\Delta$W(Zn) | 0.00000085 | -0.00000230 | -0.00000063 | -0.00000119 |
| | ppm | 0.33 | -0.89 | -0.24 | -0.46 |
| | $\Delta$t (mK) | -0.229 | -0.619 | -0.169 | -0.322 |

## 4. Comparison over the Entire Range from 0°C to 421.527°C

It is interesting to see the differences of the SPRT calibration results over the entire range from 0°C to 419.527°C between the two instruments. In order to do so the coefficients $a_8$ and $b_8$ of the deviation function must be calculated first. The deviation function for the range is as follows [6]:

$$W(t) = W_r(t) + a_8\,[W(t) - 1] + b_8\,[W(t) - 1]^2 \qquad (1)$$

where $W_r(t)$ is the SPRT reference function of the ITS-90 [function (10a) in the ITS-90] [6]. The coefficients $a_8$ and $b_8$ can be calculated from the calibration results at the TPW, FPSn, and FPZn, i. e. W(Sn) and W(Zn). The values of $W_r(t)$ at the freezing points of tin and zinc are given in Table 1 of the ITS-90: $W_r$ (Sn) = 1.89279768 and $W_r$ (Zn) = 2.56891730. Then the coefficients $a_8$ and $b_8$ are calculated by using the following two equations:

$$a_8 = \{[W(Zn)-1]^2\,[W(Sn) - W_r(Sn)] - [W(Sn) - 1]^2\,[W(Zn) - W_r(Zn)]\} / DZ \qquad (2)$$

$$b_8 = \{[W(Sn) - 1]\,[W(Zn) - W_r(Zn)] - [W(Zn)-1]\,[W(Sn) - W_r(Sn)]\} / DZ \qquad (3)$$

where:

$$DZ = [W(Sn) - 1]\,[W(Zn)-1]^2 - [W(Sn) - 1]^2\,[W(Zn)-1] \qquad (4)$$

The calculated coefficients for the four SPRTs in the comparison are listed in Table 3.

Table 3. The coefficients $a_8$ and $b_8$ of the deviation function for four SPRTs

| | SPRT S/N: | S01 | S02 | 4011 | 4054 |
|---|---|---|---|---|---|
| 6010T Bridge | W(Sn) | 1.89266267 | 1.89273958 | 1.89268367 | 1.89270354 |
| | W(Zn) | 2.56867054 | 2.56880806 | 2.56870222 | 2.56873639 |
| | $a_8$ | -1.432396E-4 | -5.906983E-5 | -1.153152E-4 | -9.242531E-5 |
| | $b_8$ | -8.962153E-6 | -6.732918E-6 | -1.389156E-5 | -1.459570E-5 |
| 1590 | W(Sn) | 1.89266145 | 1.89273827 | 1.89268415 | 1.89270348 |
| | W(Zn) | 2.56867139 | 2.56880576 | 2.56870159 | 2.56873517 |
| | $a_8$ | -1.471307E-4 | -6.053904E-5 | -1.135369E-4 | -9.155420E-5 |
| | $b_8$ | -6.139366E-6 | -6.730997E-6 | -1.528124E-5 | -1.564681E-5 |

If the coefficients $a_8$ and $b_8$ are known, it is easy to calculate W(t) at any temperature by using equation (1) directly. The W(t) at every 10°C from 0°C to 420°C were calculated for the four SPRTs from both sets of the coefficients $a_8$ and $b_8$ (6010T Bridge and 1590). Then the differences at each temperature can be calculated by using the following equations:

$$\Delta W(t) = W_{1590}(t) - W_{6010T}(t) \qquad (5)$$

$$\Delta t\,(t) = \Delta W(t) \times dt/dW \qquad (6)$$

where $W_{1590}(t)$ and $W_{6010T}(t)$ were the calculated values of W(t) at t from the set of coefficients $a_8$ and $b_8$ of 1590 and 6010T Bridge respectively. The calculated results are shown in Fig. 1. The maximum difference between the two instruments (SPRT S02 at a temperature close to 420°C) is 0.66 mK, and all of the differences are within the range of ± 1 ppm for resistance ratio.

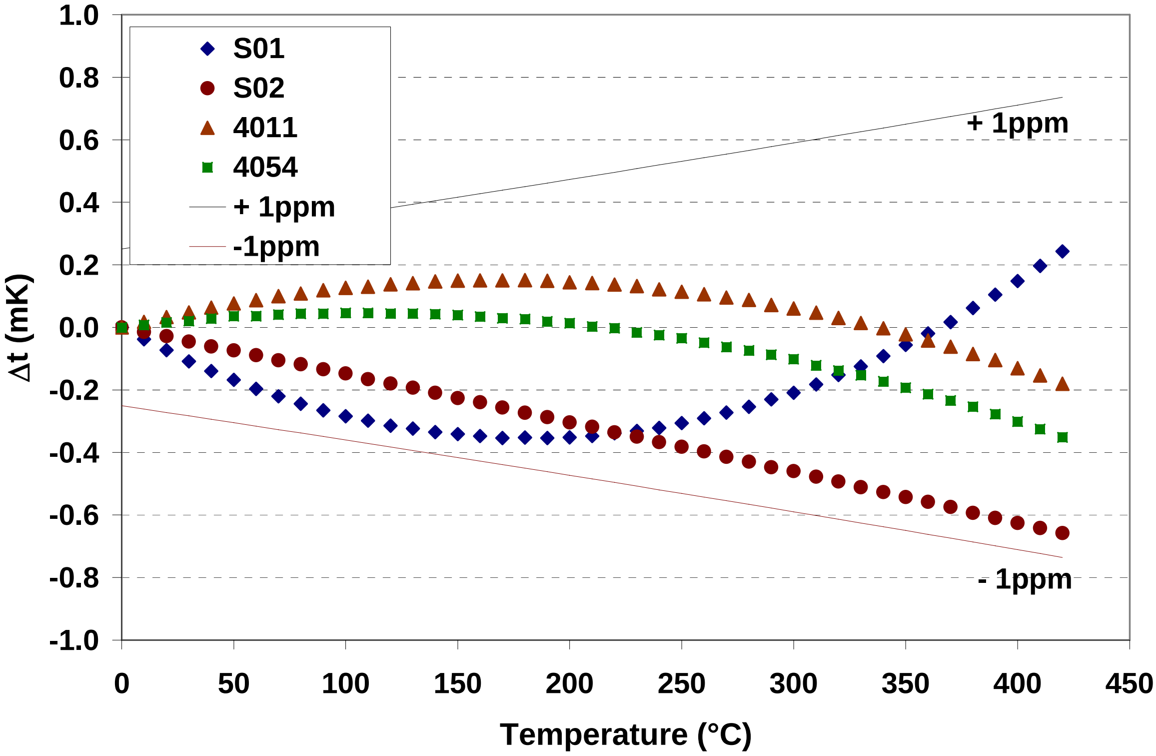

Fig. 1 Differences in SPRT calibration results between 6010T Bridge and Model 1590 for four SPRTs over the range from 0°C to 420°C

## 5. Comparison of the Estimated Uncertainties of SPRT Calibration between the Two Instruments and Discussion

The SPRT calibration uncertainties at the FPSn and FPZn were estimated using both instruments (Table 4). The uncertainty components from fixed point cells, furnaces and operations might not be the same from lab to lab. Here the estimated values are based on Hart Cal Lab conditions. The purities of both tin and zinc are higher than 99.99995% (6N5). The estimated expanded uncertainties (k=2) are 0.75 mK at FPSn and 0.94 mK at FPZn using the 6010T Bridge. If we use Model 1590 instead of the bridge, the expanded uncertainties will be 1.21 mK at the FPSn and 1.44 mK at the FPZn, only about 60% larger than those using 6010T Bridge. The uncertainty estimation made here is consistent with the direct comparison results between the two instruments in this work using four SPRTs. The maximum difference between two instruments among four SPRTs is 0.35 mK at the FPSn and 0.62 mK at the FPZn, both are smaller than the estimated total standard uncertainties at the respective fixed point (0.60 mK at the FPSn and 0.72 mK at the FPZn).

If the lowest uncertainties of SPRT calibration are required, the bridge should be used. But many SPRT calibrations do not need such low uncertainties. For example, many SPRTs are used as reference standards to calibrate other temperature probes, such as secondary standard PRTs, thermistor probes, thermocouples, or others. An expanded uncertainty of 1.5 mK (k=2) is really good enough for these SPRT calibrations. The new instrument tested in this work is suggested to be used in such cases, which saves time and cost and which is much easier to use and needs less training for calibration technicians compared to the bridge.

Table 4. The estimated uncertainties at the FPSn and FPZn for using both instruments

| Source of uncertainty | Uncertainty component (mK) | | | |
|---|---|---|---|---|
| Fixed point: | FPSn | | FPZn | |
| Instrument: | 6010T | 1590 | 6010T | 1590 |
| Reproducibility (A) | 0.200 | 0.450 | 0.300 | 0.500 |
| Impurity (B) | 0.310 | 0.310 | 0.350 | 0.350 |
| Hydrostatic correction (B) | 0.022 | 0.022 | 0.027 | 0.027 |
| Pressure correction (B) | 0.017 | 0.017 | 0.022 | 0.022 |
| Immersion (B) | 0.030 | 0.030 | 0.030 | 0.030 |
| SPRT self-heating (B) | 0.030 | 0.030 | 0.030 | 0.030 |
| Propagated from TPW (B) | 0.050 | 0.050 | 0.080 | 0.080 |
| Non-linearity of instrument (B) | 0.020 | 0.250 | 0.029 | 0.370 |
| Total B | 0.319 | 0.405 | 0.364 | 0.518 |
| Total standard uncertainty | 0.376 | 0.605 | 0.472 | 0.720 |
| Expanded uncertainty (k=2) | 0.753 | 1.210 | 0.944 | 1.441 |

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