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The Use of Thermowell Bushes at the Triple Point of Water for Improving Repeatability

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Abstract Water triple point cells are essential for realization of the International Temperature Scale of 1990 (ITS-90). There is some evidence that achieving the ultimate performance of water triple point cells may be restricted by the variation in the position of the platinum resistance thermometer at the bottom of the re-entrant well, and that the variation in position is not completely compensated for by correction to zero measurement sensing current. This comparative study focused on the use of quartz bushes (tubular sleeves around the thermometer) of two different lengths, to improve the thermal contact and to help locate the thermometer. It shows that an improvement in repeatability of the resistance readings was achieved. The experiments were conducted over a five-week period using a standard platinum resistance thermometer, a one water cell, and two different lengths of quartz bushes. The resistance measurements were performed using an Automatic Systems Laboratories F900 resistance bridge. A description of the experiment and results is given. Significant improvement in the repeatability of the measurement of resistance was observed (factor >2) when quartz bushes were used.

Keywords Bushes · Platinum resistance thermometers · Thermometry · Water triple point

1 Introduction

To obtain the ultimate performance for calibrating a standard platinum resistance thermometer (SPRT) at the water triple point, a number of subtle effects need to be taken

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into account. For example, it is necessary to make a correction for the natural isotopic variation of the water, compared to the ITS-90 specified Vienna Standard Mean Ocean Water (or V-SMOW). The reference isotopic composition was fixed in Recommendation (T1) of the CCT to the CIPM "Clarification of the definition of the kelvin, unit of thermodynamic temperature" [1] and subsequently endorsed by the CIPM [2]. All water triple point cells manufactured after that recommendation should be supplied with an isotopic analysis, or at least provided with a correction for the isotope effects to bring the cell into line with that expected for a cell filled with V-SMOW.

Another important effect that needs to be taken into account for is the self-heating of the sensing element in the platinum resistance thermometer. This arises because an electrical current must be passed through the platinum wire to determine its resistance; and there is as a consequence, a small but distinct rise in temperature above that of ambient conditions. Supplementary Information for the ITS-90 [3] describes two components: *internal* and *external* self-heating. The former is the temperature difference between the platinum sensing element and the outside wall of the protective sheath; it is therefore ONLY a function of the thermometer and not the environment in which the thermometer is placed. The latter arises because the generated heat must flow to some external heat sink, in this case, the liquid–solid interface in the cell. The total effect of self-heating is universally determined through extrapolating the resistance measured at two or more distinct currents to the value, R (0 mA) at zero current.

To obtain the best thermal contact between the thermometer and the well of the water triple point cell, and thus obtain the smallest value for the self-heating effect and the most repeatable value for R (0 mA), the Supplementary Information of the ITS-90 [3] implicitly recommends the use of close-fitting bushes that should be highly conductive and non-reactive. However, due to the relatively small effect, many thermometrists do not routinely use such bushes. For example, Renaot et al. [4] undertook an Euromet comparison of water triple point cells, but the use of bushes is not discussed. Even in later comparisons at the highest level, bushes were only used by some participants [5]. This seems to indicate that many thermometrists think that the improvement gained is marginal compared to the additional complication in using bushes. Where the internal diameter of the cell is not much larger than the outer diameter of the thermometer, the gap is small and the benefits are not great. However, a recent study [6] has shown that the use of bushes does result in an improvement over measurements without them, and that this is correlated with the gap dimension. In that work the author used quartz instead of aluminum bushes as he had previously discovered that aluminum bushes reacted with the ethyl alcohol used as the contact fluid in the triple point of water thermowell.

The work presented here seeks to demonstrate the level of improvement that might be attained in repeatability of resistance values through comparing the use of close fitting quartz bushes of two different lengths around the sensing element region of an SPRT when used in a water triple point cell.

2 Experiments

The experiment used the following key equipment: an Automatic Systems Laboratories (ASL) F900 resistance bridge, a Tinsley 5187 SA SPRT, and an Isotech water triple point cell (s/n B11-50-767). A Tinsley (nominally) 100 Ω standard resistor (Type 5684) was maintained in a thermostatted stirred oil bath at a nominal temperature of 20 °C. A schematic diagram of the experimental arrangement is shown in Fig. 1. Two close fitting quartz bushes were produced, one of 50 mm and another of 60 mm length, the outer diameter of the bushes was 10 mm, and the thermowell diameter was 11.7 mm. Use of the quartz bush in the water triple point cell is shown schematically in Fig. 2.

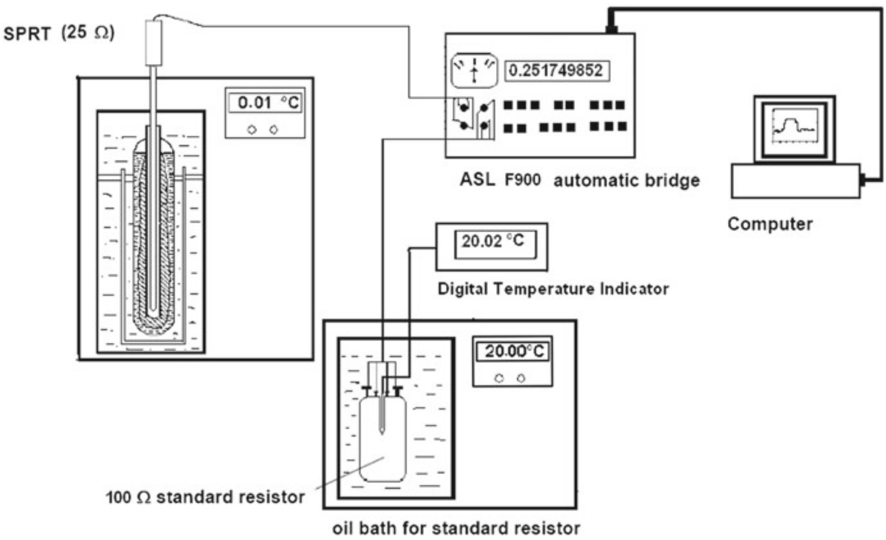

Fig. 1 Schematic diagram of the experimental arrangement

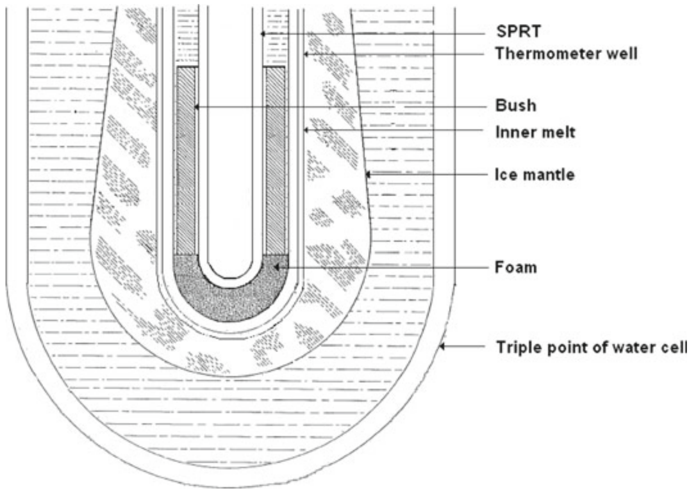

Fig. 2 Schematic diagram of the lower part of a water triple point cell with bush and SPRT

The bushes were pre-cooled, together with the SPRT in an ice-cooled tube, prior to being introduced into the thermometer well. The water triple point cell was maintained in an alcohol bath at 0 °C and was prepared 7 days before the experiments began [5]. During the experiments the ice mantle was checked both at the beginning and at the end of the measurement set to ensure that it was free from the thermometer well. The contact fluid in the triple point cell thermometer well was distilled water. A small foam plug was placed at the bottom of the thermometer well in order to prevent direct contact between the SPRT and the ice sheath where, due to buoyancy effects, it contacts the bottom of the re-entrant well [7].

The experimental procedure, in essence, was very straightforward. A reference series of data was taken from the SPRT with no bushes, followed by a second series with one bush (length 60 mm), then finally a third series with two bushes stacked on one another (total bush length 110 mm). The SPRT and the bush were pre-cooled for at least 30 min before being introduced into the thermometer well. Periodically, measurements of the standard resistor temperature were made, to make corrections for any drift (these were in reality very small as the temperature of the standard resistor changed, at most by 0.03 °C, during the whole experiment). During the measurements, the bath and thermometer were covered in an opaque black plastic sheet to eliminate the "light piping" effect of thermal radiation from external light sources. After the SPRT output had stabilized, a sequence of readings was performed, 20 min at 1 mA, 20 min at $\sqrt{2}$ mA (twice the power), and then finally another 20 min at 1 mA. A minimum of 70 readings was taken during that period. The thermometer was then removed from the thermowell for a few seconds and then reinserted, allowed to stabilize, and then the measurement sequence repeated. Ten measurements were performed without a bush, then ten with one bush, and then another ten with two bushes. The measurements for each data point took at least two days to collect.

3 Results and Discussion

The data were corrected for self-heating effects by extrapolation to 0 mA. The value for the self-heating correction, for all three conditions, was approximately (2.78 ± 0.02) mK. The bridge ratios at 0 mA are shown in Fig. 3.

A few of the first measurements of each day exhibited drifts, indicating that the thermometer/water triple point system had not yet stabilized; so to ensure consistency in data processing, all measurements taken at the beginning of each day were excluded. The standard deviation of each data set was then calculated, respectively, for the no-bush readings, the 60 mm quartz bush readings, and the 110 mm quartz bush readings. These readings are given in Table 1 and plotted in Fig. 4.

The introduction of close fitting bushes around the thermometer sensing element within the triple point of water cell significantly improves the repeatability of the resistance values measured by the SPRT because of the improved thermal contact. It is also clear that the correction for self-heating resulted in a small improvement in the standard deviation of the data, but this was not as significant as the use of bushes, at least in this experiment. Finally, it is also clear that the use of a long bush (110 mm as opposed to 60 mm) resulted in further improvement in the standard deviation of the measurement of resistance values.

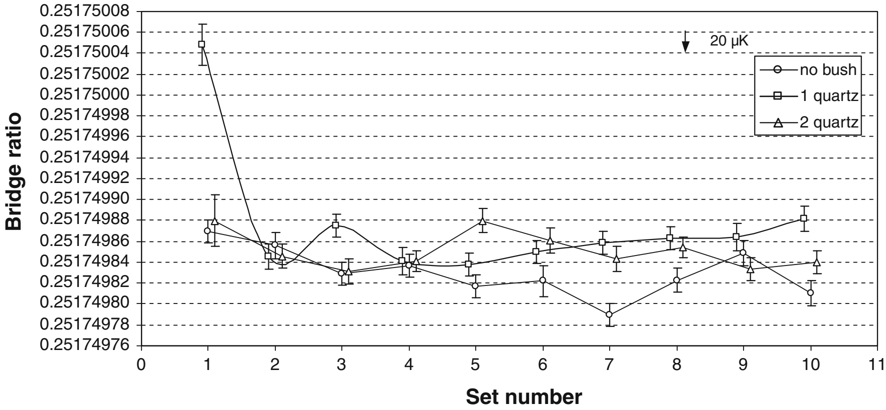

Fig. 3 Bridge ratios corrected for self-heating, with no bush, 60 mm bush (one long bush), and 110 mm bush (two bushes stacked together). Scale divisions on the *y*-axis are equivalent to 20 μK

Table 1 Standard deviations of the average resistance values under the various experimental conditions

	0 mA (corrected) Heating current, standard deviation (μK)	1 mA Heating current, standard deviation (μK)
No bush	21	26
60 mm bush	17	20
110 mm bush	10	9

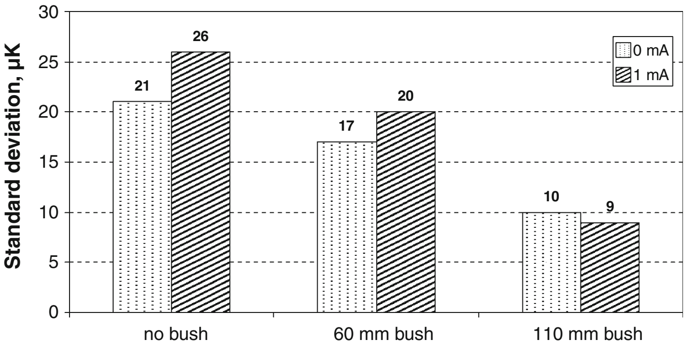

Fig. 4 Standard deviation of the average resistance values under the various experimental conditions. Same data as given in Table 1 presented graphically (excluding first data set)

4 Conclusions

For this type of thermometer, a significant advantage in repeatability can be gained through the use of a close fitting quartz bush. This can be further improved if the bush extends significantly beyond the length of the sensing element (at least twice the length). These results are strongly suggestive that close fitting bushes should be used in all measurements of water triple points to extract the ultimate in performance.

These results require confirmation through use of another thermometer (e.g., one with lower self-heating than this type of thermometer) and a different bush material. It would also be interesting to examine the effect of bushes in the use of other fixed-point cells—in particular, the triple point of mercury.

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