U.P.B. Sci. Bull., Series A, Vol. 76, Iss. 2, 2014 ISSN 1223-7027

SELF-HEATING EFFECT RESEARCH FOR A SPRT MEASURING THE TRIPLE POINT OF WATER

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This paper presents the results obtained during SPRT (Standard Platinum Resistance Thermometer) fixed point calibration at the Triple Point of Water using national standard equipments from the INM (Institutul National de Metrologie). It presents the results from the self-heating effect point of view. The purpose of this research is to determine in which manner the self-heating effect influences SPRT measurements at the fixed points, and also to compare different uncertainty evaluation methods of the self-heating influence. These studies will lead to a better SPRT (Standard Platinum Resistance Thermometer) fixed point calibration uncertainty.

Keywords: temperature, fixed points, calibration, self-heating

1. Introduction

For high accuracy SPRT measurements it is useful to know in what manner the self-heating effect influences them, determine the appropriate corrections that should be applied to the measured values, and the corrections uncertainty in order to better evaluate the uncertainties in thermometric fixed points & SPRT calibrations and to assure a reliable *national standard operation and traceability*.

Because of the fact that a it is passive, a current that passes through the resistance is needed in order to determine it's value. The effect is I^2R heating that increases the SPRT *resistance measured value* [1]. Self-heating effect is a phenomenon, which occurs when the measurement current additionally heats up the SPRT sensor. Measurement current **i** dissipates power **P** :

$$P = i^2 \cdot R \qquad (1)$$

Generated heat causes heat flux from the platinum coil to the protective sheath and further to the ambient. The resulting temperature gradient will cause a temperature increase of the platinum coil. The thermometer therefore measures the higher temperature t(i≠0) instead of actual temperature t(i=0). The purpose of the present study is to examine different methods of determining the errors caused by the self-heating effect influences on the SPRT measurements and to evaluate the accuracy of the evaluation methods used.

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2. Measured resistance values

The values are obtained using a 5699 Metal Sheath Standard Platinum Resistance Thermometer (SPRT) measuring the temperature of the Triple Point of Water materialized in a Fluke 9260 Mini Fixed-Point cell.

The Triple Point of Water is appropriate for this study for two reasons. First it is easy to obtain and second it offers the best stability for self-heating effect research.

The SPRT resistance value readings were made with F 18 Primary Thermometry Bridge. The self-heating measurement influence research can be carried out because the bridge allows the user to choose the SPRT carrier current.

Errors caused by self-heating of the element need to be minimized. Allowing sufficient time for the SPRT to stabilize and the heat to be dispersed into the surrounding medium will provide the most accurate results.

The Self-Heating parameter is the SPRT sensor self-heating effect on the realized fixed-point cell temperature. The uncertainty of this parameter is one of the components (Type B, rectangular distribution) used to assign an overall uncertainty to the fixed-point cell. The uncertainty component is calculated from making SPRT measurements with five excitation currents and calculating the range in the zero current extrapolation from the possible current combinations [2].

Figure 1 shows the measurement results carried out with a SPRT measuring the temperature of the Triple Point of Water for 90 minutes, in the identical environment. Different SPRT resistance values were measured for carrier currents from 0,1 to 2 mA. Table 1 shows the stabilized values average for a given carrier current. The smallest current in Table 1 is 0,5 mA because under this value SPRT resistance was instable, as shown in the last part the graphic in figure 1. The measured values are presented in resistance values (Ω) and the sensitivity is 0,1 Ω/°C, the difference between the values measured for 0,5 and for 2,0 mA (lowest and highest values) is 0,31 mΩ, equivalent to 3,1 mK.

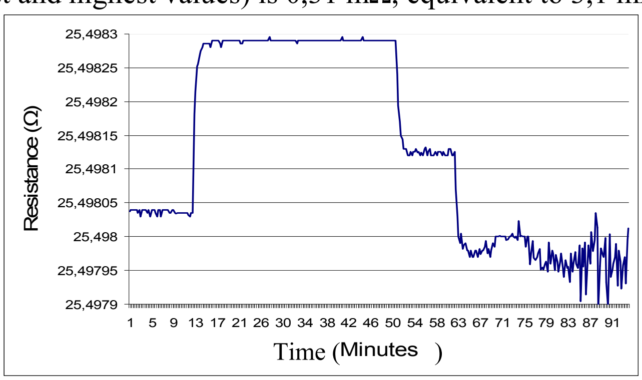

Fig. 1. SPRT resistance measured values

Table 1

Average SPRT resistance values measured for the corresponding carrier current

Carrier Current (mA)	SPRT resistance value R (Ω)
0,500	25,497980
0,707	25,498000
1,000	25,498040
1,414	25,498120
2,000	25,498290

3. Zero current resistance (R_0) ITS-90 evaluation with the two current method

In order to determine the errors caused by the self-heating effect influences on the SPRT measurements with the two current method**,** first the zero current resistance R_0 has to be evaluated. R_0 would be the measured value when the current (carrier current) that passes through the resistance is null. It is impossible to measure R_0 directly because a non-null carrier current for the resistance measurement.

More accuracy may be achieved, at more effort, by reducing the reading to the resistance which would be obtained if there were no source of power. This can be done by measuring the resistance at two currents, for example 1 mA and √2 mA the accustomed level, in the identical environment. Converted to terms of power, the zero power resistance can be extrapolated.

These measurements are then extrapolated to zero current. According to [5], 6.5, ecuation 2, This can be done using the following equation.

$$R_0 = R_1 - \frac{i_1^2 (R_2 - R_1)}{i_2^2 - i_1^2} \tag{2}$$

where:

R_0 = Zero current resistance

R_1 = Resistance measured at carrier current i_1

R_2 = Resistance measured at carrier current i_2

Table 2 shows R_0 values determined with relation (2). In this relation i_1 and i_2 are carrier current values from table 1.

Table 2

Zero current resistance (R_0) using the ITS-90 evaluation method

i_1 (mA)	i_2 (mA)	*SPRT resistance* R_1 (Ω)	*SPRT resistance* R_2 (Ω)	Zero current resistance R_0 (Ω)
1,000	2,000	25,498040	25,498290	25,4979567
1,000	1,414	25,498040	25,498120	25,4979600
0,500	1,000	25,497980	25,498040	25,4979600
0,707	1,000	25,498000	25,498040	25,4979600

1,414	2,000	25,498120	25,498290	25,4979500
0,500	2,000	25,497980	25,498290	25,4979593
0,707	2,000	25,498000	25,498290	25,4979586
0,500	1,414	25,497980	25,498120	25,4979600
0,707	1,414	25,498000	25,498120	25,4979600
0,500	0,707	25,497980	25,498000	25,4979600

The average of zero current resistance ($R_{0,\mathrm{Av}}$) values from Table 2 is 25,497958 Ω. The standard deviation of these values was calculated and can be considered as a type A standard uncertainity for R_0, caused by the dispersion of R_0 values in table 2. $u_{std}\left(R_{0,Av}\right) = 3{,}15863$ μΩ.

For an output estimate:

$$y = f\left(x_1, x_2, ..., x_N\right) \tag{3.a}$$

according to [3], 5.1.2, relation 10, we can determine the standard uncertainity this way:

$$u_c^2(y) = \sum_{j=1}^{N}\left(\frac{\partial f}{\partial x_j}\right)^2 u^2\left(x_j\right) \tag{3.b}$$

Where in our case *f* is the function from ecuation (2), *x* represents the carrier currents i_1 and i_2 and N=2; using ecuation (2) and (3.b) we obtain:

$$u_c\left(R_0\right)^2 = \sum_{j=1}^{2}\left(\frac{\partial\left(R_1 - \frac{i_1^2\left(R_2 - R_1\right)}{i_2^2 - i_1^2}\right)}{\partial i_j}\right) \cdot u^2\left(i_j\right) \tag{3.c}$$

This standard uncertainty is a result of the propagated carrier currents uncertainty $u(i_1)$ and $u(i_2)$. It represents the uncertainty related to resistance measurement component caused by the self-heating influence. Using ecuation (3.c) we obtain:

$$u_c\left(R_0\right) = \frac{2\cdot\left(R_2 - R_1\right)\cdot\frac{i_2}{i_1}}{\left(\left(\frac{i_2}{i_1}\right)^2 - 1\right)^2}\sqrt{\left(\frac{i_2}{i_1^{\,2}}\right)^2 \cdot u^2\left(i_1\right) + \frac{1}{i_1^{\,2}} \cdot u^2(i_2)} \tag{4}$$

where:

$$u\left(i_1\right) = (1/\sqrt{3})\frac{\mathrm{i}_1}{100} \text{ and } u\left(i_2\right) = (1/\sqrt{3})\frac{\mathrm{i}_2}{100} \tag{5}$$

According to [4] the carrier current accuracy is 1 % from the carrier current value. This accuracy is considered to the expandend uncertainty having a rectangular probability distribution. According to [3], 4.4.5, the carrier current standard uncertainties $u(i_1)$ and $u(i_2)$ (in table 3) are (1/√3) % from the carrier current value.

In table 3 the carrier current values (i_1 and i_2) and the SPRT resistance values (R_1 and R_2) are the same from table 2. In column 3 and 4 carrier current standard uncertainties $u(i_1)$ and $u(i_2)$ are calculated with relation (5). In column 7 the zero current resistance standard uncertainty $u_c(R_0)$ is calculated with relation (4). Two rows are highlighted in table 3. In the first highlighted row, the carrier current values 1 and √2 mA are the most used for the two current method, and for the second highlighted row the highest value for zero current resistance standard uncertainty $u_c(R_0)$ is obtained.

Table 3

Uncertainty component caused by the self-heating influence using the ITS-90 evaluation with the two current method

Carrier Current i_1 (mA)	Carrier Current i_2 (mA)	$u(i_1)$ (mA)	$u(i_2)$ (mA)	*SPRT resistance* R_1 (Ω)	*SPRT resistance* R_2 (Ω)	Zero current resistance standard uncertainty $u_c(R_0)$ (μΩ)
1,000	2,000	0,00577	0,01155	25,498040	25,498290	1,43444
1,000	1,414	0,00577	0,00816	25,498040	25,498120	2,26274
1,000	0,500	0,00289	0,00577	25,497980	25,498040	0,34426
1,000	**0,707**	**0,00408**	**0,00577**	**25,498000**	**25,498040**	**1,13137**
2,000	**1,414**	**0,00816**	**0,01155**	**25,498120**	**25,498290**	**4,80833**
2,000	0,500	0,00289	0,01155	25,497980	25,498290	0,26238
2,000	0,707	0,00408	0,01155	25,498000	25,498290	0,57987
0,500	1,414	0,00289	0,00816	25,497980	25,498120	0,27994
0,707	1,414	0,00408	0,00816	25,498000	25,498120	0,68853
0,500	0,707	0,00289	0,00408	25,497980	25,498000	0,56568

4. Zero current resistance (R_0) determined with a polynomial square fitting curve through points

In order to calculate the interpolation function $R(I_{carrier})$ five points were determined by using the SPRT resistance and carrier current values in table 1.

$$R(I_{carrier}) = 0{,}00008928 \cdot I_{carrier}^{2} - 0{,}00001721 \cdot I_{carrier} + 25{,}49796695 \qquad (6)$$

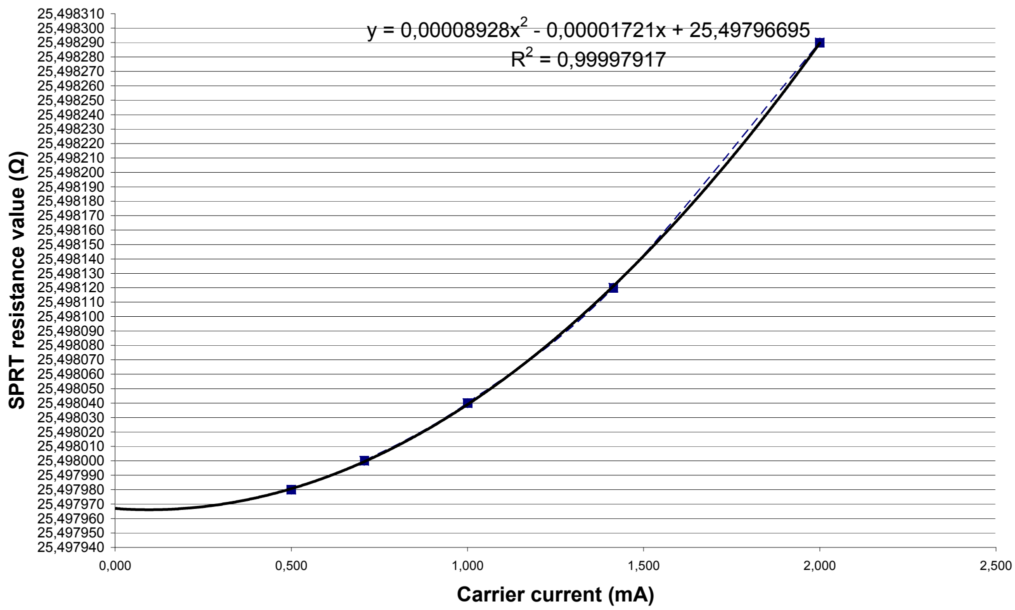

Fig. 2. Measured resistance values as a function of carrier current

The R_0 (R for a carrier of 0 mA) value calculated with the *polynomial square fitting curve through points* is 25,49796695 Ω.

5. Resistance values Self-Heating corrections

Table 4

Zero current resistance (R_0) using the two current method (method A) and a polynomial square fitting curve through points (method B)

R_0 - A (Ω)	R_0 - B (Ω)
25,497958	25,497967

The SPRT measured resistance corrections calculated with values from table 1 (R values for relation (7)) and 4 (R_0 values for relation (7)) are shown in table 5. The correction for $I_{carrier}$=1 mA is highlighted because this is the typical used value. The relation for the corrections in table 5 is the following:

$$C = R - R_0 \tag{7}$$

Table 5

Measured resistance values Self-Heating corrections (C) for the five carrier currents using the two current method (method A) and a polynomial square fitting curve through points (method B)

Carrier Current (mA)	Correction - A (mΩ)	Correction - B (mΩ)
0,500	-0,02200	-0,01305
0,707	-0,04200	-0,03305
1,000	**-0,08200**	**-0,07305**
1,414	-0,16200	-0,15305
2,000	-0,33200	-0,32305

6. Conclusions

The evaluation of self-heating effect is very important for the SPRT measurements accuracy. In order to evaluate these influences two methods were used: the two current method and a polynomial square fitting curve through points. The zero current resistance (R_0) is used for the determination of the corrections applied to the measured resistance values.

The two current method is easier to use because only two resistance values (one pair) have to be measured in order to obtain the zero current resistance (R_0). In this paper 10 resistance values pairs were used. The temperature correction standard uncertainty obtained from the standard deviation of the 10 R_0 values (table 2) calculated with the two current method is 31,5863 μK. The maximum temperature correction standard uncertainty obtained for one R_0 value calculated with the two current method is 48,0833 μK (table 3 - in temperature units). With this method the uncertainty evaluation is also easier.

The corrections for the self-heating effect are shown in table 5 for both methods. For the typical $I_{carrier}$=1 mA the measured temperature corrections in temperature units are C_A=-0,8200 mK and C_B=-0,7305 mK. The difference between the 2 methods for one value is 0,0895 mK.

R E F E R E N C E S

[1]. *Henry E. Sostmann*, fundamentals of thermometry part iii the standard platinum resistance thermometer

[2]. *G. F. Strouse*, NIST Special Publication 250-81, Standard Platinum Resistance Thermometer Calibrations from the Ar TP to the Ag FP, NIST, January 2008.

[3]. ISO/IEC GUIDE 98-3:2008(E*), Uncertainty of measurement —Part 3:Guide to the expression of uncertainty in measurement (GUM: 1995),* ISO/IEC, 2008.

[4]. F18 Thermometry Bridge Operator's Handbook, Isotech North America, Issue 4

[5]. 5680/5682/5699 Metal Sheath Standard Platinum Resistance Thermometer User's Guide, Fluke Corporation, Hart Scientific Division, 2005.

[6]. *Jovan Bojkovski,* Uncertainties related to resistance measurement, SMD, Bruxelles, Belgium, October 2011.
[7]. xxx JCGM 200:2008, International vocabulary of metrology — Basic and general concepts and associated terms(VIM), (VIM3), Joint Committee for Guides in Metrology- Working Group 2 (JCGM/WG 2), 2008 .
[8]. *L. Crovini, H. J. Jung, R. C. Kemp,S. K. Ling, B. W. Mangum and H. Sakurai*, The Platinum Resistance Thermometer Range of the International Temperature Scale of 1990, Metrologia, 1991.
[9]. The BIPM key comparison database Clasification of Services in Thermometry, May 2010.