Corrections of reducing the uncertainty of the self-heating in cryogenic temperature measurements of the highest accuracy

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Abstract

Self-heating of resistance thermometers is a well-known phenomenon, which occurs when the measuring current additionally heats up the sensing element. The self-heating temperature increase can be corrected by basic two-current method. However, in measurements of the highest accuracy, uncertainty of the self-heating correction, achieved by basic two-current method, may not be sufficient. More advanced methods for self-heating correction are proposed, based on the use of more than two different currents .

Introduction

Cernox thermometers are widely used for cryogenic temperature measurement of the highest accuracy. The self-heating effect is basically a temperature phenomenon, but it is measured as a resistance difference, so we can analyze the phenomenon by two methods, in terms of temperature or in terms of resistance. In this paper, we choose the latter method to analysis the phenomenon, since measured Cernox thermometer resistance is usually first corrected for self-heating and only afterwards transformed to temperature. In this paper, the uncertainty of the self-heating correction of a Cernox thermometer in cryogenic temperature measurements is calculated by four different methods.

Theoritical Background

The basic two-current method, based on the quadratic relation between the self-heating value and the current, is used to correct the self-heating effect . Typically, the resistance is the first measured with current, the resistance is measured with current and the measurement with the first current is usually repeated to check the stability. Zero-current resistance can be calculated as:

$$R_0 = 2R_1 - R_2 \qquad (1)$$

And the self-heating correction uncertainty in terms of resistance can be calculated as:

$$u_{SH}^2 = 4u_{R_1}^2 + u_{R_2}^2 + \left(\frac{4(R_1 - R_2)}{I_1}u_{I_1}\right)^2 + \left(\frac{4(R_1 - R_2)}{I_2}u_{I_2}\right)^2 \qquad (2)$$

In measurements of the highest accuracy, uncertainty of the self-heating correction, achieved by the basic two-current method, may not be sufficient. In order to further decrease the uncertainty, the improved methods with more than two different currents are proposed. The resistance can be calculated using the least-square fit.

$$R_0 = \frac{\sum_{i=1}^{n} R_i \sum_{i=1}^{n} I_i^4 - \sum_{i=1}^{n} R_i I_i^2 \sum_{i=1}^{n} I_i^2}{n\sum_{i=1}^{n} I_i^4 - \sum_{i=1}^{n} I_i^2 \sum_{i=1}^{n} I_i^2} \qquad (3)$$

$$U_{sh}^2 = \sum_{i=1}^{n}\left(\frac{\partial R_0}{\partial R_i}u_{R_i}\right)^2 + \sum_{i=1}^{n}\left(\frac{\partial R_0}{\partial I_i}u_{I_i}\right)^2 \qquad (4)$$

Equation (3) can be used to calculate when the measurement currents are more than two. The self-heating uncertainty can be calculated by equation (4).

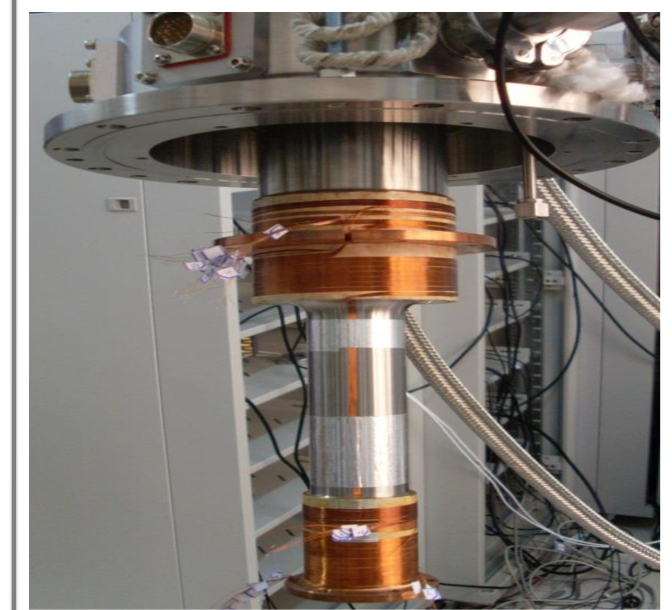
Conclusion

- Cernox thermometer self-heating is a significant factor in high accuracy cryogenic temperature measurement that cannot be eliminated, but it can be corrected by two-current method.
- More advanced methods for self-heating correction can decrease the self-heating uncertainty from 0.695mK to 0.480mK at 8K, and from 0.838mK to 0.637mK at 10K.
- The advanced methods can reduce the uncertainty of self-heating correction significantly compared with the basic two-current method, but the use of more than three currents produced only a modest additional improvement in uncertainty.

Experimental Setup

CX-SD Thermometer

- **Sensor Dimensions:** 3.175×1.905×1.080mm
- **Wire Length:** 25.4±6.35mm
- **Features:** Low magnetic field induced errors Excellent resistance to ionizing Excellent stability



In order to obtain the cryogenic temperature, a new cryostat was designed.

Measurment Procedure

A series of measurements were performed to calculate the self-heating correction uncertainty at cryogenic temperatures by the presented theory. The measurements were performed with a Cernox thermometer in 8K and 10K.

The self-heating correction was performed using 4 different methods:

(1) basic two-current method with currents 50 and $50\sqrt{2}\ \mu A$
(2) three-current fitting with currents 20, 30 and 70 μA
(3) four-current fitting with currents 20, 30, 50 and 70 μA
(4) five-current fitting with currents 20, 30, 50, 60 and 70 μA

Results

The Uncertainty of Self-heating calculated by different methods

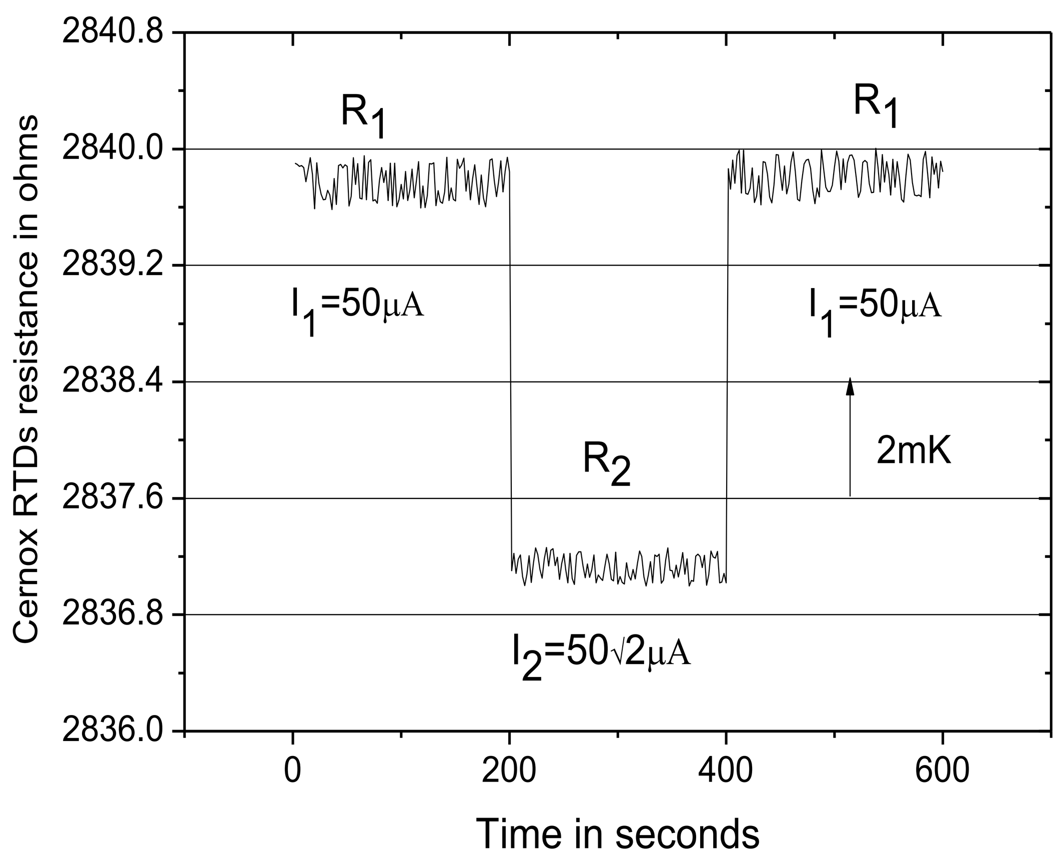


Figure 1. The basic two-current method

Figure 1 shows the measurement results of the Cernox thermometer resistance at 8K by basic two-current method.

The resistance R_1 is first measured with 50 μA , Then resistance R_2 is measured with $50\sqrt{2}\ \mu A$ .And the measurement with the first current is usually repeated to check the stability.

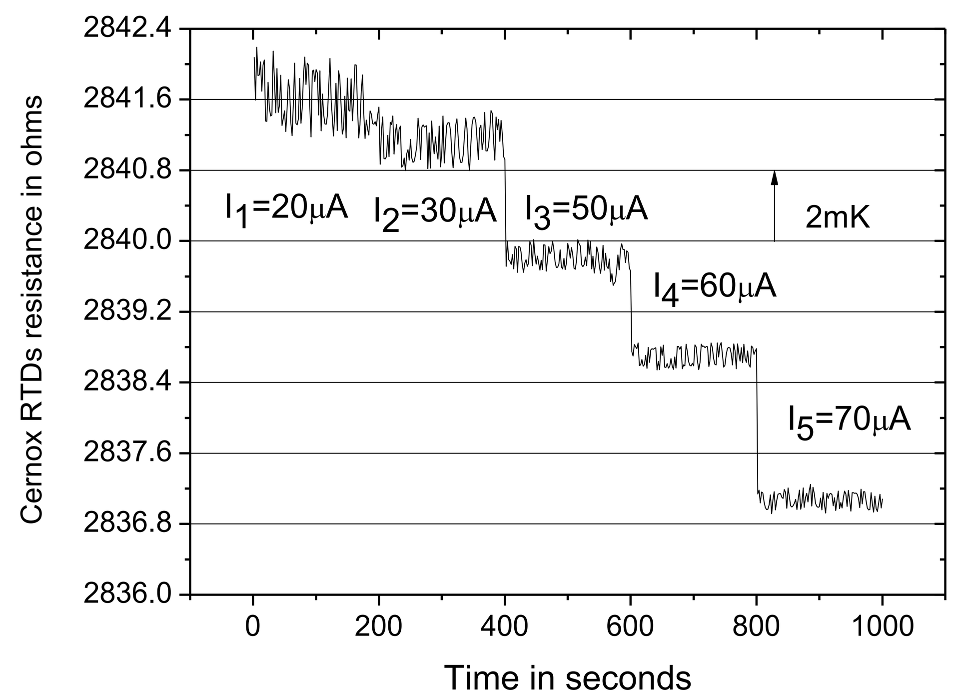


Figure 2. The advanced methods with more than two currents

Figure 2 shows the results of the advanced methods with more than two different currents.

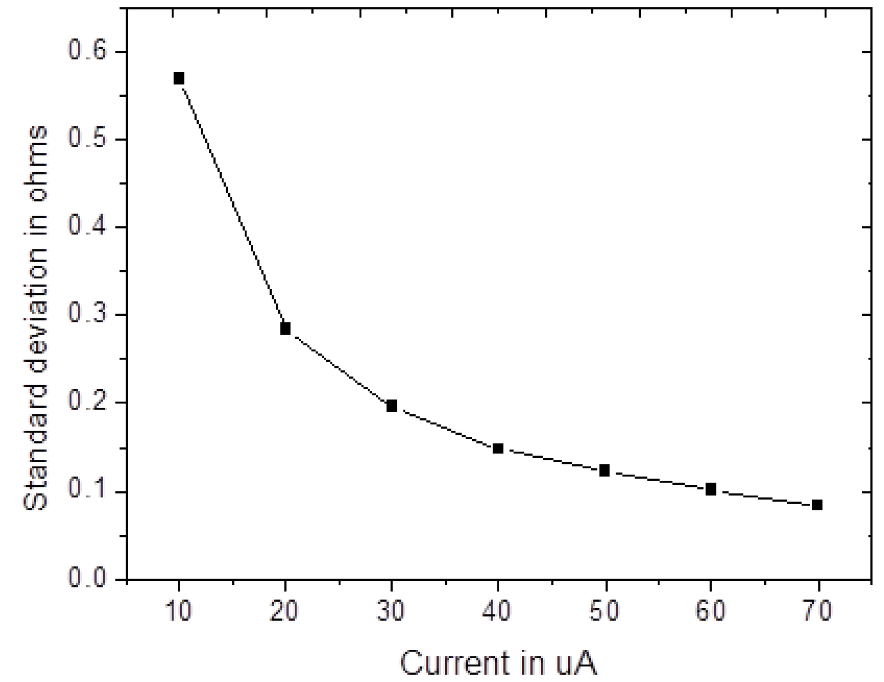


Figure 3. Standard deviation of the resistance of the Cernox thermometer at 8K

It can be clearly observed that the increase of measurement current will lead to the decrease of the resistance fluctuation and it can be further proved by figure 4. The fact indicates that the use of higher currents in the basic two-current method resulted in a significant decrease of self-heating correction uncertainty.

Method number	Self-heating correction uncertainty(mK)	
	8K	10K
1	0.695	0.838
2	0.522	0.694
3	0.481	0.637
4	0.480	0.637

Table 1 Uncertainty of the self-heating correction for four methods in 8K and 10K

The uncertainty of the thermal resistances at different temperatures installed by Varnish was analyzed in **Table 1.** It is remarkable that the uncertainty of the thermal resistance decreasing with the increasing of the temperature, while the relative uncertainty of the thermal resistance for different temperatures are almost equal. The uncertainty of the thermal resistance at all temperature points are less than 3%, it means that the calculation results of the thermal resistance is credible.