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Accuracy of the Approximation Function Deduced from the Fixed 3-Points Calibration Delivered with the Cernox™ Sensor

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Abstract

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INTRODUCTION

This work was initiated by a request made by ITER to investigate whether non-calibrated cernox™ sensors [1,2] meet the ITER requirements that have a relatively wide error budget on the measurement of temperature, for instance it is ±0.2 K in the range 4.2 K to 10 K. By analysing the CERN thermometer database it was found out that at the 4.2 K point, the individual calibration and the manufacturer data is within +/-0.1 K for 99.39% of a sample population of about 5700 sensors; it is then very likely that the 3-point manufacturer calibration is sufficient to obtain an approximation function that meet relatively wide requirements like those of the ITER machine.

Several applications require the measurement of temperature over a range that can be as wide as 1.7 K to 300 K and this paper presents a first attempt to determine the accuracy that may be achievable by using the CERN thermometer database and the 3-point calibration delivered with the cernox™ sensors. The cernox™ sensors have a wide dispersion of their physical characteristics and do require individual approximation functions to achieve acceptable accuracies. The individual approximation is derived by defining a set of reference functions that are used to build the individual algorithms. The 3-point data is used as anchors, the accuracy thus improves around the 3-anchor temperatures of 4.2 K, 77 K and 300 K. The final result is strongly dependent on the quality of the 3-point manufacturer data, implying that by performing an accurate 3-point calibration it may be possible to improve the accuracy.

Preliminary results indicate that, without any additional calibration, accuracies of ±0.1 K between 1.7 K to 5 K and ±1 K between 5 K to 77 K are obtained. This is comparable and in some cases better than what can be obtained with some interchangeable sensors, such as standard industrial-type platinum resistances, silicon diodes or CLTS.

This investigation is made by using the data compiled during the calibration of cernox™ sensors for both the LHC and CERN's general use. The sample size is made of more than 5'900 sensors, which should provide adequate statistics, although there may exist a bias due to the LHC requirement of procuring cernox™ sensors with a smaller tolerance on the variation of resistance than that proposed in the manufacturer catalogue or due to variations in the procedures over time when manufacturing the sensors.

COMPARISON BETWEEN INDIVIDUAL CALIBRATIONS AND 3-POINT DATA

The CERN calibration station [3] has an equivalent resolution smaller than 0.001 K below 10 K and for cernox™ sensors the reproducibility observed is ±0.01 K in the 1.6 to 100 K temperature range, the individual calibration have an uncertainty of +/- 0.25%. The 3-point data supplied with the cernox™

sensors are obtained by measuring in open baths of liquid Helium and Nitrogen , and a room temperature oven is used for ambient temperature, without any uncertainty specification. The data is supplied with 3 significant digits, corresponding to a resolution of 0.007 K at 4.2 K and 0.4 K for the other fixed points 77K and 300K.

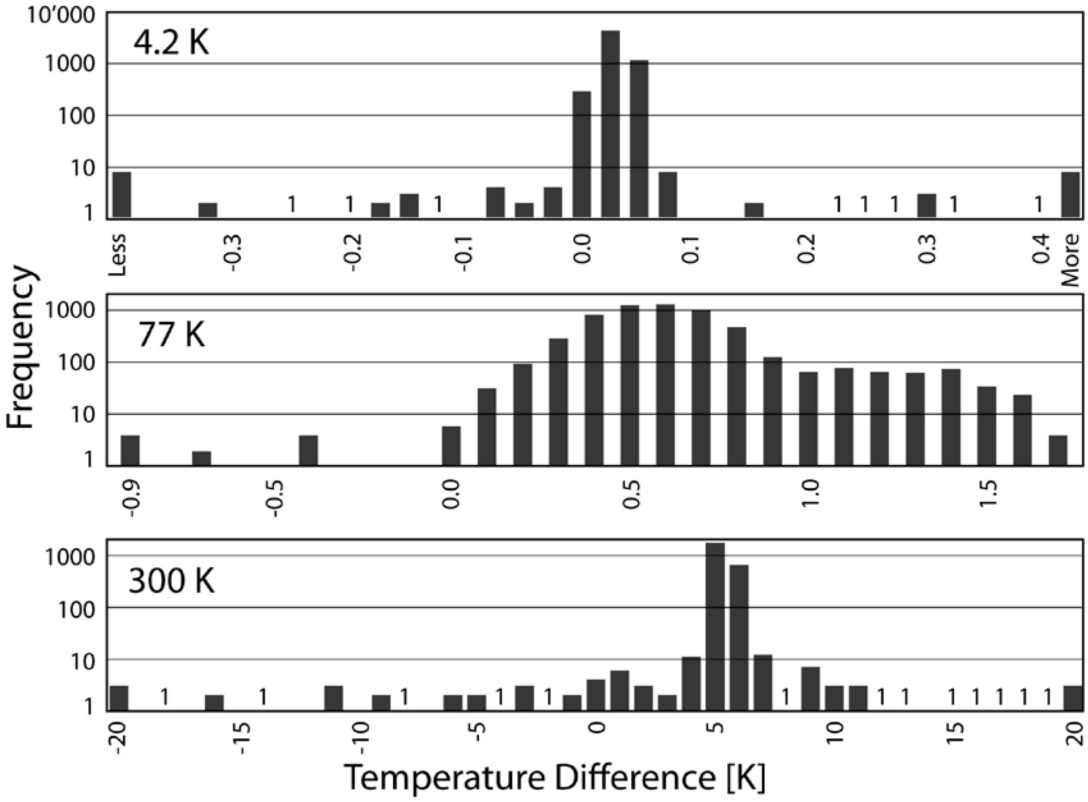

Figure 1 Frequency versus temperature difference between the cernox™ 3-point data and the corresponding temperature calculated from the individual calibration at 4.2 K, 77 K and 300 K. A logarithmic scale on the bin/frequency scale is used to better visualize the spread on the temperature difference.

The two closest measurements around 4.2 K, 77 K and 300 K are selected from the individual calibration stored in the CERN instrumentation database and a linear interpolation is then used; the calibration points are sufficiently close to be able to neglect errors due to the non-linearity of the resistance versus temperature transfer function for the cernox™ sensors.

The spread between the cernox™ 3-point data and the individual calibrations is shown in Figure 1. A systematic difference of 0.025 K, 0.6 K and 5 K is observed respectively for 4.2 K, 77 K and 300 K. The sensors are clustered around a relatively narrow range of values, for instance at 4.2 K, 99.39% of the sensors are within 0.1 K and 99% are within a width of ± 0.025 K. There is then an excellent correlation between the individual calibrations and the 3-point manufacturer data. This is a strong indication that an individual approximation function can be constructed from both the 3-point data and the cernox™ data stored in the CERN database.

DATA MANIPULATION

Figure 2 shows all the data points for which resistance values at both 4.2 K and 77 K exist; the sharp variations at the extremities of the data for 4.2 K are due to less populated regions that are probably not composed of sensors delivered for the LHC project. Most of the cernox™ sensors were part of a special supply; the main constraint was a resistance to be bounded in between 27’500 ohm and 17’500 ohm at the temperature of 1.7 K. This also results in narrower spreads at any temperature, although for any resistance at 4.2 K there exists a very wide range of corresponding resistance values at 77K as can be observed from the relatively wide cloud for the 77 K data in Figure 2.

A set of reference functions is defined by subdividing the sensors in families according to their range of resistance at the temperature of 4.2 K and 77 K. The typical family size used is either 100 units or 200 units for 4.2 K or 77 K respectively. The reference functions are defined by the sensors located at the family boundaries (i.e. maximum and minimum resistance for a family). The individual approximation between 4.2 and 77 K is constructed from a set of 4 functions.

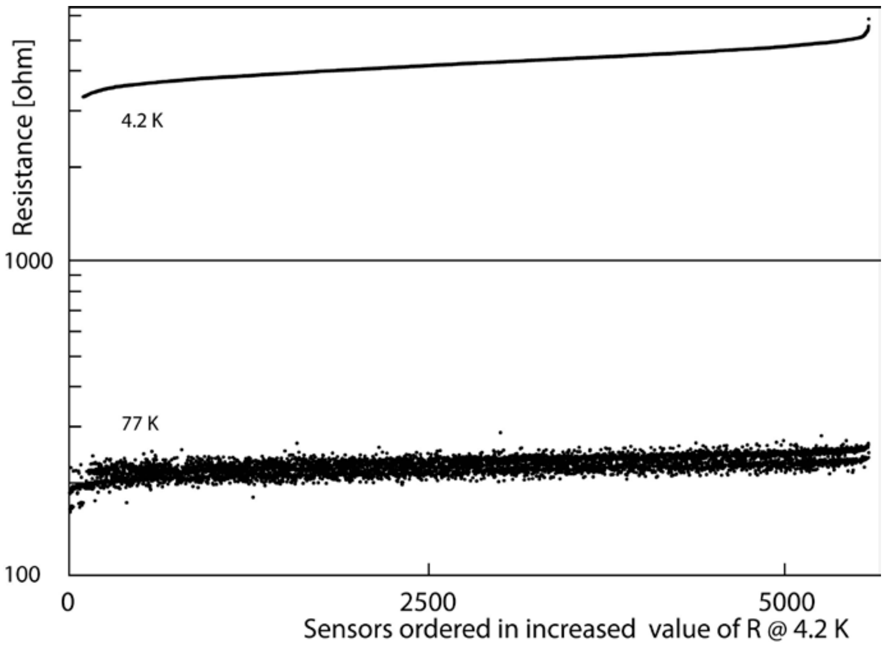

Figure 2 Cernox™ resistances at both 4.2 K and 77 K ordered in increasing value for its resistance at 4.2 K.

The predictive approximation function at either the 4.2 K or 77 K point is defined by a weighted addition of the maximum and minimum functions using the multiplying factor shown in Figure 3. For calculating the temperature of intermediate resistances, the approximations at 4.2 K and 77 K are weighted according to the logarithm of the resistance between 4.2 K and 77 K (see Figure 3). In the future a similar technique will be tried in order to extend the range to 300 K.

APPROXIMATION FOR UNCALIBRATED SENSORS

To test the validity of the method, the CERN data was used both for generating the reference functions and for providing the data for the non-calibrated sensors. The difference between the approximated and individually calibrated data is used to provide a first indication of the accuracy that can be attained.

Ten test sensors are selected randomly among the 4.2 K points at 4270 ohm and 4250 ohm. The corresponding pair of 4.2 K reference cernox™ sensors have a resistance of 4262 ohm and 4277 ohm. The 20 ohm difference for the test sensors is chosen in order to determine whether the prediction is improved by taking into account the systematic difference of 0.025 K at 4.2 K (see Figure 1).

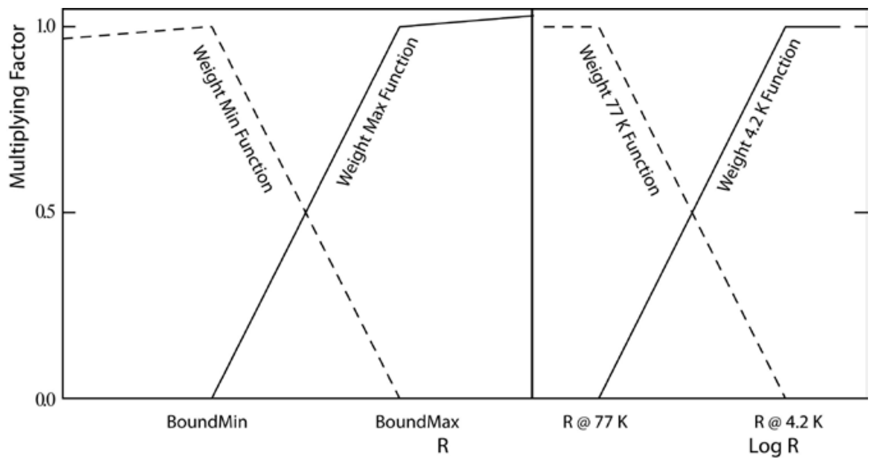

Figure 3 Weighting of approximation. Left: in between of bounds at either 4.2 K or 77 K; Right: weight for varying temperature or resistance

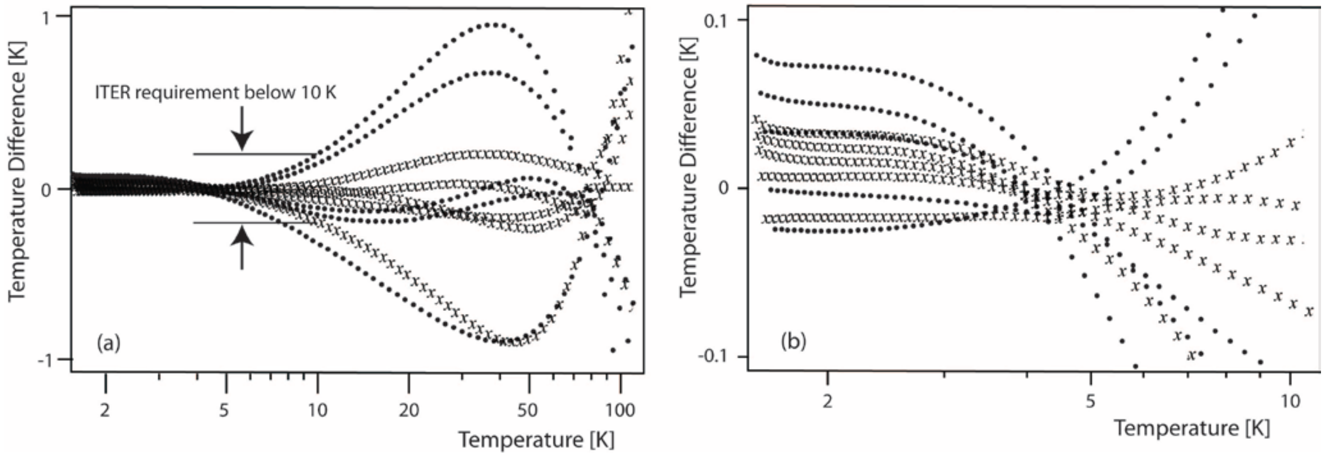

Figure 4 Comparison between the prediction and the individual calibration for 10 cernox™ sensors. The families are given by the 4.2 K resistance provided with the sensor; filled dots: 4270 ohm, “x” symbol: 4250 ohm.

The 10 test samples have 77 K resistance points that range from 212 ohm to 252 ohm, this range already covers most of the observed resistance variations that is 190 ohm to 260 ohm. For the approximation, a set of 3 pairs of 77 K reference functions are required.

The accuracy of the prediction is shown in Figure 4, below 4.2 K down to 1.55 K the cernox™ characteristics can be predicted to within ±0.1 K. By taking into account the systematic difference shown in Figure 1, the accuracy is improved by a factor of 2, indicating that still better results may be attained with more accurate 3-point calibration data.

CONCLUSION

This paper presents an attempt to predict the individual cernox™ sensor’s approximation function from the 3-point data supplied. The accuracy of the predicted fits is comparable to what can be obtained with certain types of interchangeable temperature sensors. This opens the door to employ cernox™ sensors over a temperature range of 1.7 K to 300 K without investing in the cost associated with an individual calibration. In particular the fits predict surprisingly well the characteristics at the very low end of the temperature range.

The quality of this analysis may be strongly biased with the particular requirements requested by CERN in a narrower dispersion of the resistance at the 1.7 K temperature; and it applies only to sensors satisfying the LHC constraint that the resistance should be bounded between 27’500 ohm and 17’500 ohm, at the temperature of 1.7 K.

This work will be extended by, on one hand calculating the predictions up to room temperature and by significantly increasing the sample size for the tested thermometers.

ACKNOWLEDGMENT

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