CHARACTERISTICS OF RUSSIAN CRYOGENIC TEMPERATURE SENSORS UNDER MAGNETIC FIELDS

Dedikov Yu.A.[†], Filippov Yu.P.[‡] and Kytin G.A.[†]

[†]National Scientific and Research Institute for Physical Technical and Radio-technical Measurements - VNIIFTRI, Mendeleyevo 141570, Moscow Region, Russia

[‡]Joint Institute for Nuclear Research, Dubna 141980, Moscow Region, Russia

Abstract

The report presents the results of our activity during many years in the field of cryogenic thermometry and metrology applied to superconducting devices operating in the magnetic fields e.g. subsystems of accelerators and detectors. The equations to calculate the temperature shifts due to the magnetic fields for temperature sensors are given.

1 INTRODUCTION

Physical installations with superconducting magnets require efficient systems for monitoring the operation characteristics of the cooled devices and cryogens. The value of temperature is one of the main parameters to determine the state of the cryogen or cooled device. This report presents the information about four types of Russian commercially available cryogenic resistive temperature sensors investigated at cryogenic temperatures and under magnetic fields up to 9 T. They are platinum, rhodium-iron, carbon-glass and carbon TVO-resistors.

2 CHARACTERISTICS OF THE SENSORS

The detailed characteristics of all the thermometers are presented in [1,2]. Briefly they are as follows.

Rhodium-iron (RIRT) and platinum (PRT) resistive temperature sensors. The measured range is from 0.5 K to 373 K and from 13.8 K to 373 K for RIRT-1 and PRT-5 modifications; resistance at 273.15 K is 100 Ohm, self heating - 2 mK, diameter - 3.7 mm, length - 40 mm, mass - 2 g, accuracy - ± 1 mK for both sensors; stability is 0.5 mK and 0.3 mK per year for RIRT-1 and PRT-5, correspondingly. The sensors RIRT-1 and PRT-5 are incorporated in the Russian national standard of the International Temperature Scale of 1990 (ITS-90). Other modifications of these thermometers - RIRT-2, RIRT-3, RIRT-4 and PRT-5V, PRT-4, PRT-4M are also produced. They are intended for calibration with the reduced accuracy, precision laboratory measurements and operation in radiation environment; their length can be of 20...40 mm at the same diameter. For example, the accuracy of RIRT-2 and PRT-5V is 5 and 10 mK, correspondingly.

Carbon-glass resistive temperature sensor: model CRT-2. Its characteristics are as follows: the measured range is from 2 K to 300 K; diameter - 2.2 mm, length - 14 mm, mass - 1 g, self-heating - ≤ 3 mK; accuracy - 10 mK at (0.35 - 4) K, 30 mK@(4 - 27) K, 100 mK@(27 - 80) K and 1.5 K@300 K; stability - 3 mK/year at (0.35 - 4) K and 10 mK/year@(27 - 80) K. This sensor is intended for laboratory measurements, particularly, at the high magnetic field and irradiation.

Carbon resistive temperarure sensor based on the TVO resistor. This type of the thermometer is well known [1,2,3,4,5]: for example, several hundreds TVO are used successfully in superconducting accelerator of nuclei - Nuclotron at JINR, Dubna [4]. Physical configuration is a rectangular prism of 8 mm length and 1.3×2.4 mm^2 cross-section with two copper leads. It has ceramic and glass coats to provide a hermetic seal, and can be used in the environment combining moisture, corrosion, vibration, high and low temperatures. One of the features of the TVO-sensors is zero inductance and high electric insulation resistance - up to 5000 MOhm. The nominal values can be of 910, 1000 or 1100 Ohms. The uncertainty caused by instability of the resistance is estimated as $\Delta T/T \le \pm 0.25$ % for the first class and ±0.5 % for the second one. It is admitted to warm the sensor to 373...400 K without changing its calibration. This sensor can be recommended for routine measurements in the high magnetic field and radiation environment.

3 TEMPERATURE SHIFTS DUE TO THE MAGNETIC FIELD

The investigated sensors can be divided into two groups: TVO and CRT with negative temperature coefficient and low temperature shift due to the magnetic field, $\Delta T = T(B) - T(0)$, and RIRT and PRT with positive temperature coefficient and comparatively high ΔT at low temperatures. Let us consider these groups.

CRT and TVO sensors. An important advantage of both carbon thermometers is that their readings practically do not depend on the orientation in the magnetic field. The values of $\Delta T/T(0)$ for CRT with lowest and highest sensitivity are shown in Figure 1. The analysis has shown that the values of the magneto-resistance, $\Delta R = R(B)-R(0)$, for CRT sensors are described very accurately by the equation

$$\Delta R = A\times B^{n}\,, \qquad \textbf{(1)}$$

where $\ln A = \Sigma a_i(\ln T)^i$, $n = \Sigma b_i(\ln T)^i$, $i = 0 - m$, and $m = 2$ for the range from 2 K to 5 K and $m = 4$ for the range from 2 K to 80 K. The corresponding deviations of the experimental points from curve (1) do not exceed ±3 mK for the batch of 8 investigated sensors. To determine the parameters in Equation (1), it is necessary to have the initial calibration curve at B = 0 and to measure the magneto-resistance, for example, in 5 points for the range (2-5) K and 10 points for (20-80) K. Usually, there are no problems to calculate the value of the magnetic field, B, and estimate its direction in the point of the sensor mounting within a real system. This allows one to calculate the corresponding temperature shift due to the magnetic field $\Delta T = \Delta R(dT/dR)$.

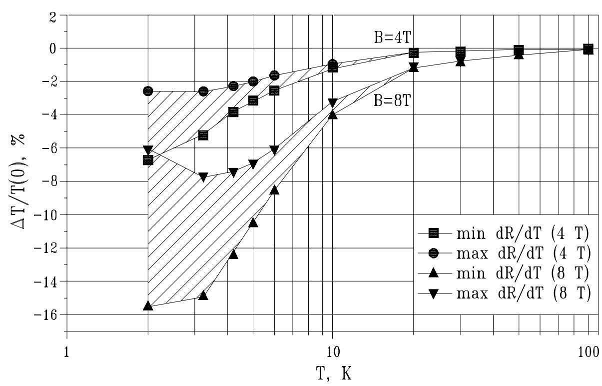

Figure 1: Relative temperature shift, $\Delta T/T(0)$, due to the magnetic field, B, versus temperature, T, for CRT-2.

Noteworthy that the behavior of the arbitrary chosen CRT-2 sensors in the magnetic field at helium temperatures can be described by the equation

$$\Delta T = A_0(B,T) + A_1(B,T)/S \qquad \textbf{(2),}$$

where $S = (T/R)(dR/dT)$ is dimensionless sensitivity. Eq. (2) is valid for the ranges (2-6) K and (0-8) T. The maximum deviation of the experimental points does not exceed 0.02 K, see Figure 2. To calculate ΔT by means of Equations (2), it is necessary to have the calibration curve at B = 0 and to use an iteration algorithm to find the thought value at the estimated B.

The values of relative magneto-resistance $\Delta R/R(0)$ and $\Delta T/T(0)$ for the batch of 8 TVO sensors can be found in [6]. For example, $\Delta R/R(0)$ can be described by the equation $\Delta R/R(0) = e^{(C0-C1T)}$. Noteworthy that dependence of ΔT on B and T for these sensors looks similar on those shown in Figure 2 for CRT-2. It is illustrated with Figure 3 where new experimental data for

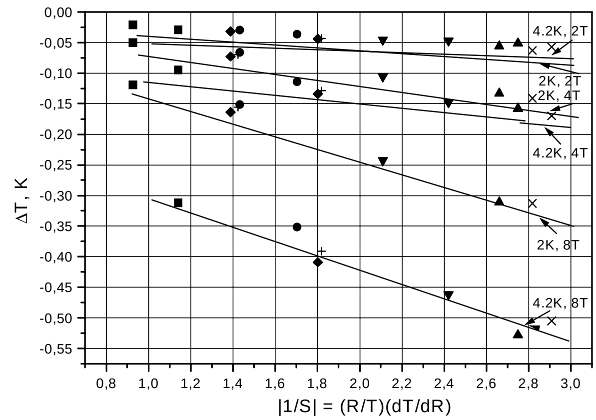

Figure 2: Temperature shift, ΔT, due to the magnetic field, B, versus sensitivity, 1/S, for different CRT-2.

five TVO sensors are presented. One can see that all the experimental data can be fitted by a very simple equation:

$$\Delta T = (C_2B - C_3)/S \qquad \textbf{(3),}$$

which is valid as the first approximation for the ranges (1.8 - 4.2) K and (0 - 9) T: the maximum deviation of the majority of the experimental points does not exceed 0.02 K. The coefficients are as follows: $C_2 = 0.0089$, $C_3 = 0$ at (0 - 2.25) T, $C_2 = 0.023$, $C_3 = 0.032$ at (2.25 - 4.5) T and $C_2 = 0.0263$, $C_3 = 0.047$ at (4.5 - 9) T. The calculations according to this equation are in good agreement with the results based on the data [6] for eight TVO sensors tested in the range from 1.8 K to 4.2 K: the differences at S = 1 are 0.002 K at 3 T, 0.005 K@ 6 T and 0.015 K@ 9 T.

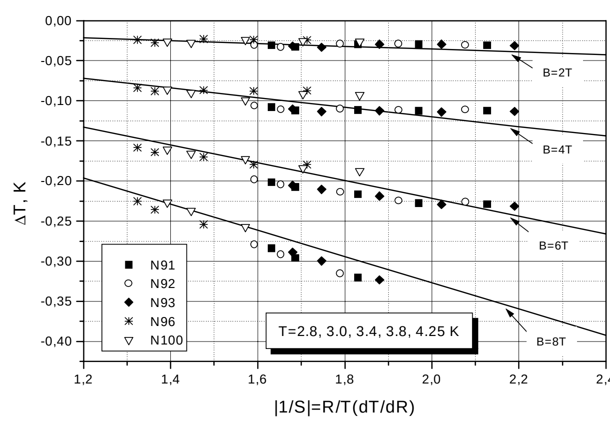

Figure 3: Temperature shift, ΔT, due to the magnetic field, B, versus sensitivity, 1/S, for different TVO sensors

To obtain a more accurate calculation, it is necessary to carry out a calibration of a TVO sensor in the magnetic field. Thus, if the equation

$$\Delta R/R(0) = \Sigma A_{ik}(\ln T)^i\, B^{[th(C_iT)+1]} \qquad \textbf{(4)}$$

is used, one can calculate $\Delta T(B, T)$ with $\delta T < \pm\, 0.01$ K.

RIRT and PRT sensors. Temperature shifts, ΔT, due to the perpendicular magnetic field and $\Delta T/T(0)$ for RIRT are illustrated by Figures 4 and 5. One can see that these values are significantly larger than for CRT-2 and TVO. However, the way to determine ΔT for RIRT with the accuracy of 0.01 K can be derived. Processing the experimental data for this sensor has shown that if the calibration curve for RIRT is known for the case B=0, the values $\Delta T(B, T)$ can be calculated with the accuracy of 0.01 K for the ranges (3 - 80) K and (0 - 7) T by Equation (5)

$$\ln\Delta R(B, T) = \ln A + n(\ln B) + p(\ln B)^2 \qquad \textbf{(5)},$$

where A, n and p depend only on the temperature. Influence of the orientation of the RIRT thermometers in the magnetic field can be taken into account by the Q-factor which is the ratio between the values of ΔT at perpendicular and parallel orientation of the magnetic field

$$Q = \Delta T_{\perp}/\Delta T_{\parallel} = 1.053 + 0.103\ln T \qquad \textbf{(6)}.$$

This is valid for the temperatures from 3 K to 20.4 K with the deviation of about ±0.5 %.

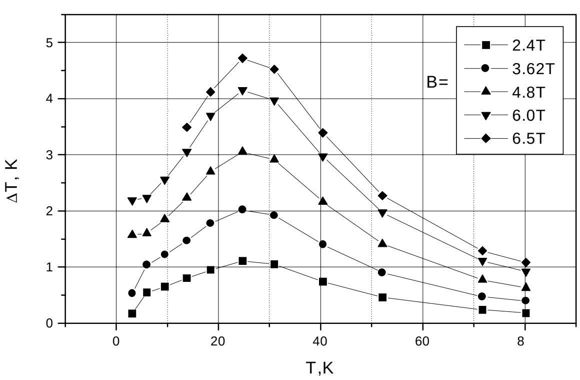

Figure 4: Temperature shift, ΔT, due to the perpendicular magnetic field, B, versus temperature, T, for RIRT.

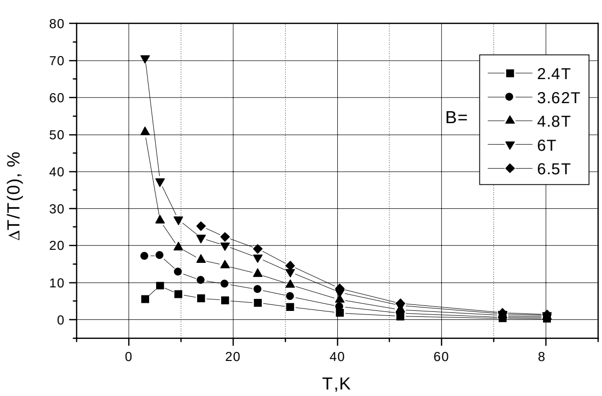

Figure 5: Relative temperature shift, ΔT/T(0), due to the perpendicular magnetic field, B, versus temperature, T, for RIRT.

As for the platinum thermometers, their behavior in the magnetic field can be described by the relation [7]

$$\Delta W_M(B, W) = \Sigma A_i(\ln W)^i \cdot B^{n(W)},\ i=0...12 \qquad \textbf{(7),}$$

where $W = R(T)/R(273.15\ K)$ is the standard relative resistance of the sensor at B=0. The deviations of the ΔW_M-values from the experimental points do not exceed 0.02 K for the ranges (30 - 190) K and (0 - 7) T. Influence of the orientation of the PRT sensors in the magnetic field and a procedure to calculate the temperature shifts due to the magnetic field can be found in [7]. The typical values of $\Delta T/T$ for them in the perpendicular magnetic field are approximately as follows: 26 % at 20.2 K and 6.5 T, 2.3 % @ 40.3 K and 6.5 T, 0.28 % @ 80 K and 6.5 T [7].

5 CONCLUSIONS

Russian cryogenic thermometers are able to provide reliable measurements of temperatures in physical and industrial installations under conditions combining magnetic fields and cryogenic temperatures of a wide range: their choice depends on the technical requirements. To calculate the temperature shifts due to the magnetic fields for the carbon sensors with the accuracy about 0.02 K, one can use relations (2), (3) and the initial calibration curves T(R,B=0). More accurate calculations for the considered sensors are possible by means of equations (1), (4)÷(7): in this case one needs to obtain several experimental points to determine the corresponding coefficients.

REFERENCES

[1] Yu.A.Dedikov and Yu.P.Filippov, Characteristics of Russian Cryogenic Temperature Sensors, in: Proc. of the ICEC18, Mumbai, India, 2000, p.627-630.

[2] M.S er, Characteristics of the TVO Temperature Sensors, in: Proc. of the ICEC 17, Bournemouth, UK, 1998, p. 699-702.

[3] V.I.Datskov and J.G.Weisand II, Characteristics of Russian Carbon Resistance (TVO) Cryogenic Thermometers, Cryogenics, 34, 1994, p.425-428.

[4] A.M.Baldin et al., Cryogenic System of the Nuclotron - a New Superconducting Synchrotron, in: Advances in Cryogenic Engineering, vol.39a, Plenumm Press, New York, 1993, p. 501-508.

[5] Ch.Balle, J.Casas, J.M.Rieubland, A.Suraci, F.Togny and N.Vauther, Influence of Thermal Cycling on Cryogenic Thermometers, in: Advance in Cryogenic Engineering, 45, 2000, Plenum Press, New York (to be published).

[6] Yu.P.Filippov and A.K.Sukhanova, Behaviour of the TVO Temperature Sensors in the Magnetic Fields and under Gamma Irradiation, in: Proc. of the EPAC2000, Vienna, Austria, p.2278-2280.

[7] G.S.Abilov and I.A.Razhba, Characteristics of the Low Temperature Resistive Thermometers in Magnetic Fields and the Ways of Approximation, in: "Metrologic Support of Thermal Explorations at Low Temperatures", Moscow, VNIIFTRI, 1988, p.59-73 (in Russian).