BEHAVIOUR OF THE TVO TEMPERATURE SENSORS IN THE MAGNETIC FIELDS AND UNDER GAMMA IRRADIATION

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Abstract

The well known TVO temperature sensors were irradiated by a gamma source up to the total dose of 0.1, 0.3 and 0.5 MGy. After these experiments the post-radiation behaviour of the sensors was estimated. Besides, several tests of the TVO-carbon sensors with different specific sensitivities were carried out in the magnetic fields (parallel and perpendicular to the sensor package) up to 9 T in the temperature range from 1.6 K to 4.2 K. The obtained results are discussed.

1 INTRODUCTION

Modern high energy accelerators and their detectors frequently operate in the environment of high radiation fluences, magnetic fields and cryogenic temperatures. One of the temperature sensors which can meet such requirements as long term stability, suitable sensitivity, high radiation tolerance/resistance, relatively low temperature shift due to the magnetic field and reasonable costs, is a TVO resistive temperature sensor [1 - 7]. Thus, references 3 and 5 demonstrate its high radiation resistance during irradiation by the fast neutrons fluence of more than $F_n = 10^{15}$ n/cm^2 at the helium and nitrogen temperatures. However, investigations on the influence of big doses of gamma irradiation on the characteristics of this sensor are at the initial stage [6]. In particular, it is shown in reference 6 that the relative radiation shifts, δT/T, of the TVO sensors during irradiation up to 1 MGy can be within or near the value of 0.3% for the whole temperature range from 2 K to 300 K. One can also conclude that the annealing effect reveals for these sensors after an enormous dose of 1 MGy and warming up from 77.3 K to the room temperature: the maximum temperature shifts at 300 K reached 2.8 K or even 4.5 K. It is of practical importance to have an information about post irradiation behaviour of the sensors after the doses of gamma irradiation smaller than 1 MGy, and this is one of the subjects of this report.

As for the behaviour of the TVO sensors in the magnetic field, there are contradictions in the known references 1 and 2. Thus, it is shown in [2] that the relative temperature shift due to the magnetic field, ΔT/T, at the inductance of 6 T and 4.2 K is less than 1%, and the orientation of the sensor does not influence on its readings. By the way, the value, mentioned in [1] for the same conditions, is 3 times larger for the perpendicular orientation; and changing the orientation to the parallel leads to decreasing the corresponding value by 2 times approximately. The results of additional investigations [7] have shown that the readings of the TVO sensors do not practically depend on their orientation in the magnetic field up to 9 T in the range from 1.8 K to 4.24 K. However, the values of ΔT/T can reach from 3% to 6%, for example, at B = 6 T and T = 4.2 K: the higher the sensitivity dR/dT, the lower the equivalent temperature shift ΔT/T. The way of calculating the magneto-resistance, ΔR/R(T,B) as the function of the temperature and inductance to estimate the values of the temperature shift due to the magnetic field ΔT for the TVO temperature sensors in the ranges from 1.6 K to 4.2 K and up to 9 T is another subject of this report.

2 EXPERIMENTAL SET-UP

The calibration system AK-6.25 [6] with the reference rhodium-iron resistance thermometer RIRT-1 has been used to calibrate the temperature sensors. The accuracy of this sensor is 2 mK for all the temperature range.

The gamma irradiation experiments were carried out at the Frank Laboratory of Neutron Physics, JINR. The Cesium-137 gamma source with the dose rate of 0.46 Gy/s at the average energy of about 0.661 MeV in liquid nitrogen, and - 0.50 Gy/s @300 K, was used. The GeLi gamma dosimeters have been used around and within the cryostat to find the dose. The accuracy to determine the γ-dose is about ±10%.

A solenoid superconducting magnet consisting of two coaxial sections is used for measurements in the magnetic fields. The maximum inductances in the centre of the solenoid are about 9 T at 4.2 K and 11 T@1.5 K. The solenoid is supplied by a stabilised current source with U = 6 V and I = 70 A. The LMK Hall sensor is used to measure the magnetic field.

3 POST IRRADIATION BEHAVIOUR AFTER GAMMA DOSES UP TO 0.5 MGY

First of all, it is necessary to stress that no selection was made for the tested TVO sensors: they were taken arbitrary from the batch produced and packed at the plant. For comparison, the results of the post irradiation measurements after radiation of the sensors in liquid nitrogen up to ≈ 1 MGy, in particular, are presented in Table 1 borrowed from [6]. These measurements were performed in one day and in two/four weeks after completing the irradiation process. Before this, the sensors, irradiated in liquid nitrogen, were warmed up to the room temperature, and the measurements were done as follows: first, at 300 K, then in liquid nitrogen, afterwards in liquid helium. We did not keep the sensors in liquid nitrogen or liquid helium. They were warmed up to 300 K again and remained at this temperature until the new measurements were carried out. The comparison was made with the initial values obtained during the calibration procedures.

Table 1: Post irradiation comparison for the TVO sensors irradiated up to the dose of 1 MGy at 77.3 K

Temperature, K	4.2 K		77.3 K		300 K	
Interval after irradiation	1 day	2 weeks	1 day	2 weeks	1 day	4 weeks
Type of sensor	Temperature shift, δT, mK					
TVO(V3)	11	4	-275	-225	364	2760
TVO(V6)	5	13	-177	30	790	4480

One can see that the maximum temperature shifts, observed in 4 weeks at 300 K, reached from 2.8 K to 4.5 K. These values for the sensor, irradiated at the room temperature, were 1 K and 4.6 K measured in 1 day and 4 weeks after irradiation, correspondingly [6]. Two months after the irradiation was over, the readings of all the sensors were approaching the initial calibration curves [6].

As mentioned above, the aim of the present research was to estimate a possibility of the sensor to reproduce the calibration values after irradiation up to 0.1, 0.3 and 0.5 MGy with respect to the readings which had been measured before irradiation. For this 11 TVO sensors were irradiated at the room temperature to initiate the maximum temperature shift due to irradiation.

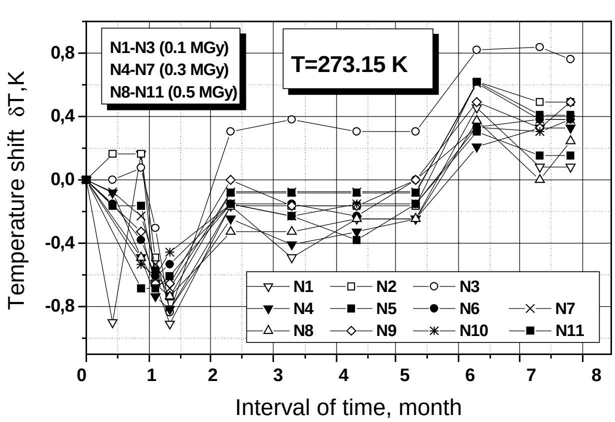

Figure 1: Temperature shifts at 273.15 K due to γ-radiation vs interval after completion of the irradiation

The obtained results for T=273.15 K are presented in Figure 1. These results have shown that all the irradiated sensors demonstrate a tendency to increase their resistance during the first month, probably, due to some defects in the material caused by irradiation: the maximum temperature shifts of minus (0.7±0.2) K correspond to the period of 1.25 months after completing the irradiation. Afterwards, annealing has been revealed for all these sensors: the maximum values of ΔT became from +0.2 to +0.8 K in 6.25 months. One can stress that these values are significantly smaller with respect to the ones mentioned in Table 1 for 1 MGy, 300 K and 1 month.

The results for T=77.2 K are presented in Figure 2. On can see that the behaviour of the sensors looks qualitatively as at T=273.15 K: the maximum temperature shifts are within the value of ±0.5%. Taking into account the previous experience [6], one can assume that this conclusion can be valid for the helium temperatures as well.

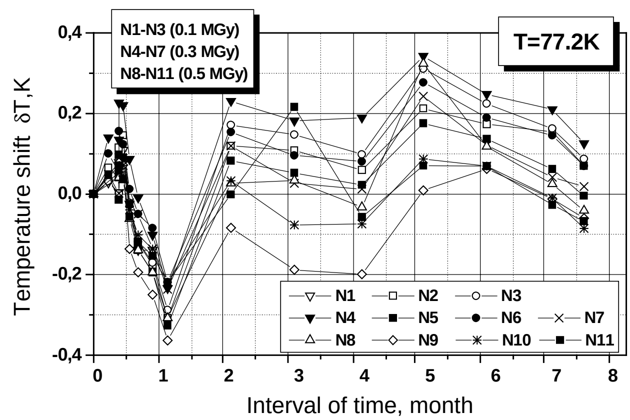

Figure 2: Temperature shifts at 77.2 K due to γ-radiation vs interval after completion of the irradiation

4 MAGNETO-RESISTANCE

There were 8 TVO tested sensors with different values of sensitivity dR/dT in the ranges from 1.56 K to 4.24 K and up to 9 T. The values of dR/dT were as follows: from -1430 Ohm/K to –13890 Ohm/K at 1.8 K and from –238 Ohm/K to -1047 Ohm/K at 4.24 K.

In principle, the relative equivalent temperature shift due to the magnetic field is expressed as $\Delta T/T(B, T) = \Delta R/R(1/S)$ where R is the resistance at the inductance B=0, $\Delta R = R(B) - R(0)$ is the magneto-resistance and S is the dimensionless sensitivity, $S=T/R(dR/dT)$. As shown in Reference 7, this expression is valid for the TVO sensors as the first approximation: the corresponding deviations are within or near ±0.02 K for the majority (80 %) of the experimental points obtained in the ranges from 1.8 K to 4.24 K and up to 9 T for the batch of eight TVO, at least. In order to calculate the values of ΔT/T, it is necessary to analyse the behaviour of ΔR/R at different T and B.

The ΔR/R- curves versus B at T=const are shown in Figure 3: they are the Boltzman functions

$$\Delta R/R = (A_1 - A_2)/(1 + e^{(B-k1)/k2}) + A_2 . (1)$$

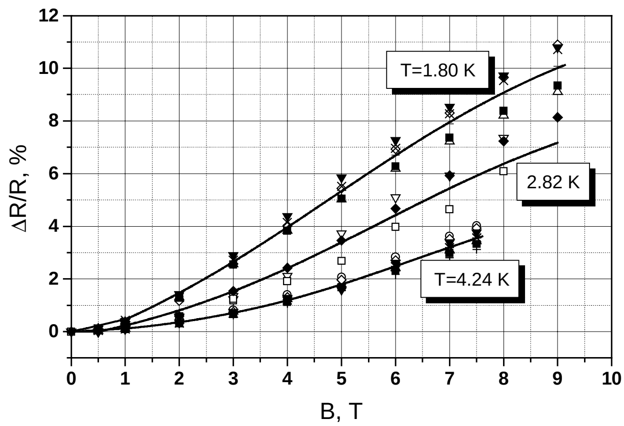

Figure 3: Relative magneto-resistance vs inductance

Here and below the "filled" and "open" points correspond to the perpendicular and parallel orientation of the sensors in the magnetic field. The corresponding coefficients are: A_1= - 2.995, A_2=13.087, k1=4.789 and k2=2.917 at T=1.80 K and A_1= - 0.3487, A_2=5.767, k1=6.314, k2=2.120 at T=4.24 K. The maximum deviations of the experimental points for different sensors of parallel and perpendicular orientations in the magnetic field are about ±0.3% for T=4.24 K and ±1% for 1.80 K. The value of 0.3% is in a good agreement with the uncertainty caused by the instability of the TVO resistors. In its turn, the deviation of ΔR/R=1% at T=1.8 K yields $\Delta T_{max}\approx$0.01 K and $\Delta T_{max}\approx$0.03 K for the sensors with the highest and lowest sensitivity.

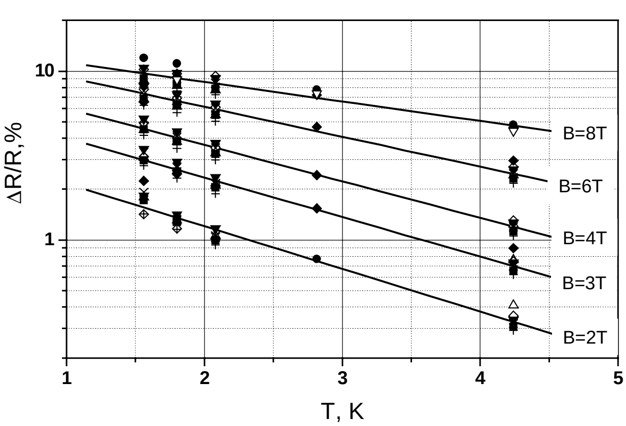

Figure 4: Relative magneto-resistance vs temperature

The ΔR/R- curves versus T at B=const are shown in Figure 4. These curves are the power functions

$$\Delta R/R = 10^{(C1 - C2 \bullet T)} \quad . \qquad (2)$$

The coefficients are: C1=0.837, C2=0.234 at 3 T and C1=1.142, C2=0.177 at 6 T, for example. One can see that the maximum deviations of the experimental points from this function are about from 0.3 % to 1%.

Thus, if the B-value is estimated, the reading of the sensor R(B, T) and calibration curve T=T(R, B=0) are known, one can find the sought real temperature T=T(R, B). The temperature shifts ΔT/T can be as follows: ΔT/T = - (5.7 ÷ 13.9)% at 1.80 K & 9 T; ΔT/T = - (2.8 ÷ 6.4)% at 4.24 K & 6 T; ΔT/T = - (0.8 ÷ 1.7)% at 4.24 K & 3 T.

5 CONCLUSIONS

The tested TVO resistive temperature sensors have demonstrated high radiation resistance: their post radiation shifts δT/T are within or near the values of 0.5% at T = 77.2 K and 0.3% at T = 273.15 K after gamma irradiation up to big doses - 0.5 MGy ($E_\gamma \approx$ 0.661 MeV) at 293 K. These values of δT/T can not be more at the helium temperatures.

To estimate the equivalent temperature shifts ΔT/T for the TVO sensors due to the magnetic fields of any direction, one can use the power (2) or Boltzman (1) functions for the relative magneto-resistance ΔR/R and the initial calibration curve T = T(R, B=0). With maximum deviations from 0.01 K to 0.03 K for the majority (about 80%) of the experimental points, this is valid for the ranges from 1.56 K to 4.24 K and up to 9 T.

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