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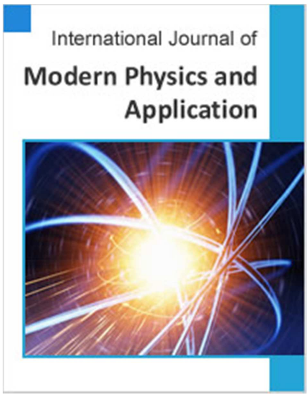

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Calibration of Temperature Sensors for BARC, Mumbai Using In-House Developed Magnetoresistance Setup at TIFR, Mumbai

Arun Patade[1], Kadayam Venkatraman Srinivasan[2], Devendra Buddhikot[1], Anindya Chakravarty[3], Vijay Arolkar[2]

[1]DCMP&MS, Tata Institute of Fundamental Research, Colaba, Mumbai, India
[2]Low Temperature Facility, Tata Institute of Fundamental Research, Colaba, Mumbai, India
[3]Cryo-Technology Division, BARC, Mumbai, India

Email address
kvsrini@tifr.res.in (K. V. Srinivasan)

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Abstract
Cryogenic temperature sensors of various types covering the entire range of measurement right from the room temperature down to 4.2 K needs to be calibrated to meet the stringent requirements on temperature control in most cryogenic applications. For some critical applications in BARC, Mumbai such as the newly developed Helium Liquefaction/Refrigeration system, many temperature sensors were calibrated using a magnetoresistance setup designed and developed at TIFR, Mumbai. The sensors are calibrated against a pre-calibrated temperature sensor. Both the pre-calibrated sensor and the sensor to be calibrated are connected to the temperature controller and the calibration data are acquired by varying temperature at small intervals from 4.2 K to 300 K. The data acquisition program is written in LabView®. This paper presents the calibration set-up, procedure, the quality assurance applied, the results of the calibration campaigns and a description of the usage of the calibrated temperature sensors.

1. Introduction

The performance of a sensor is often evaluated by its degree of measurement accuracy. The absolute accuracy of a sensor is an important parameter to be considered when choosing the type of sensor to be used in cryogenic applications. The calibration information can then be used to correct for temperature sensor measurement errors through adjustments in the data acquisition system software. For some critical applications in BARC, Mumbai such as the newly developed Helium Liquefaction/Refrigeration system [1], many uncalibrated silicon diode temperature sensors were needed to be calibrated for stringent operating requirements in the temperature range of 4.2 to 300K. This paper presents the calibration set-up, procedure, the quality assurance applied, the results of the calibration campaigns and a description of the usage of the calibrated temperature sensors.

2. Methodology

The un-calibrated (sample) sensor is mounted on the sample holder which also has a calibrated Cernox® sensor. The temperature is scanned from 4.2K (boiling point of liquid helium at atmospheric pressure) to 300K (room temperature) at an incremental of 2K and calibrated as discussed below.

2.1. Calibration

The output of a temperature sensor is a voltage corresponding to the temperature measured by the sensor. Hence, representing the relationship between voltage and temperature more accurately assures better temperature readings. Three aspects of using a cryogenic temperature sensor are very critical to its optimum performance. These include proper mounting of the sensor, correct joining of lead wires/ connecting wires and thermal anchoring of these lead wires. A pre-calibrated Cernox® sensor was used for calibrating the sample sensors.

2.2. Calibration Procedure

Using the two channel temperature controller, data from the calibrated Cernox® sensor is acquired. Uncalibrated (sample) sensor is also connected to the same temperature controller. To read the data from the uncalibrated sensor, a dummy temperature curve is allotted to the uncalibrated sensor. While scanning the temperature, the data from both calibrated and the uncalibrated sensors are acquired and stored. The temperature of the calibrated sensor is stored as TEMP#1 with the corresponding output as resistance (RES), similarly, the temperature of the uncalibrated sensor is stored as TEMP#2 with the corresponding output as voltage (VOLT). The calibration data for the sample sensor is VOLT vs TEMP#1. The calibration facility allows PC-controlled calibration of cryogenic temperature sensors in the temperature range from 4.2 - 300K steps of 2K.

3. Experimental Setup

The in-house developed magnetoresistance setup [2] can go up to a lowest temperature of 1.5 K and β = 8T. This setup includes components such as a cryostat, in-house fabricated variable temperature insert (VTI) a two stage rotary vacuum pump and a Lakeshore® make, model: 340 temperature controller. A desktop PC using General Purpose Instruction Bus (GPIB) with a suitable PC card is used for communication with the temperature controller. LabVIEW® software is used for data acquisition from the setup to the PC while ORIGIN® software is used for scientific curve plotting and data analysis.

3.1. Cryostat

The outer vacuum chamber and the liquid nitrogen shielding vessel is made of aluminium. The outer chamber (at ambient temperature), the liquid nitrogen chamber and the liquid helium chamber are thermally isolated from each other by a vacuum better than 10^{-5} mbar. The evaporation of liquid helium during the cool down of the cryostat from 77 K to 4.2 K is about 2.5 litres. The typical cross sectional view of the cryostat and the actual cryostat is mentioned as Figure 1 & 2 respectively.

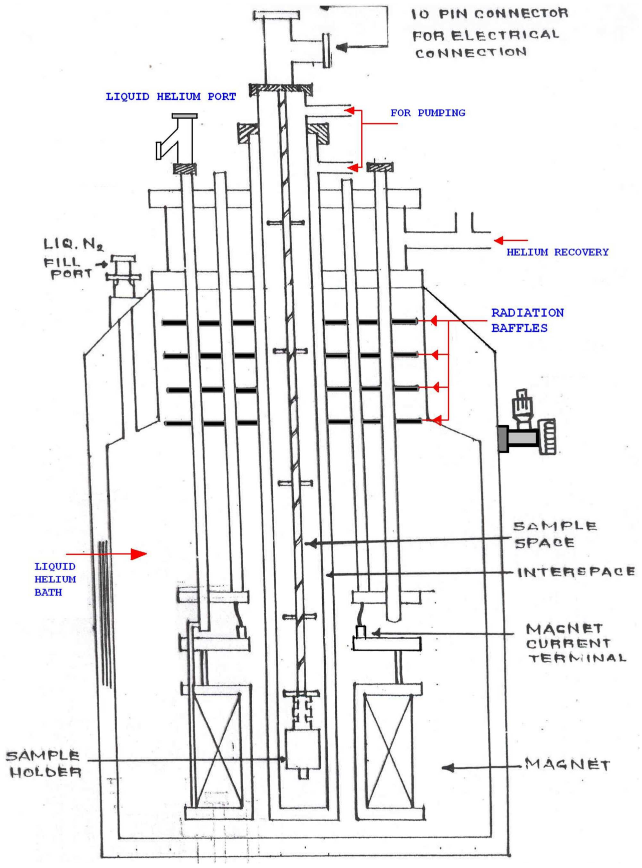

Figure 1. *Cross sectional view of the cryostat.*

Figure 2. *View of the cryostat.*

3.2. Variable Temperature Insert (VTI)

The un-calibrated (sample) sensor is mounted on the in-house fabricated sample holder of Variable Temperature Insert (VTI), which has a calibrated Cernox® sensor already mounted, is then inserted into the helium cryostat. The figure 3 istab the sketch of the in-house fabricated VTI and the Figure 4 is the actual photograph of the same.

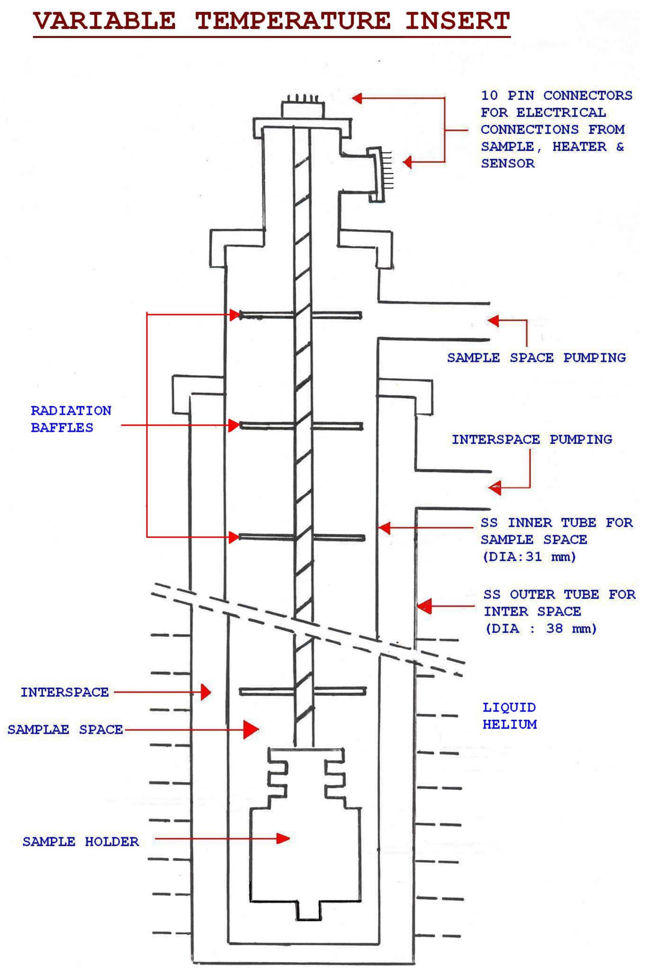

Figure 3. *Schematic of the in-house fabricated Variable Temperature Insert (VTI).*

Figure 4. *In-house fabricated Variable Temperature Insert (VTI).*

3.3. Heat Sinking / Thermal Anchoring

Efficient heat sinking or thermal anchoring is essential, as the heat flowing through the connecting leads can create an offset between the sensor and the true sample temperature, thermal anchoring of the connecting wires is necessary to assure that the sensor and the leads are at the same temperature as the sample [3]. Connecting wires should be thermally anchored at several temperatures between room temperature and cryogenic temperatures using thermal baffles of VTI to guarantee that heat is not being conducted through the leads to the sensing element. The calibrated *Cernox®* bobbin type sensor is directly mounted on the sample holder as shown in the Figure 4 & 5. The sample (un-calibrated) sensor is thermally anchored to the sample holder using GE Low Temperature Varnish, which has excellent bonding properties, good electrical and chemical resistance, along with good resistance to thermal cycling. The temperature variation is achieved using a 50 Ohm Manganin Wire.

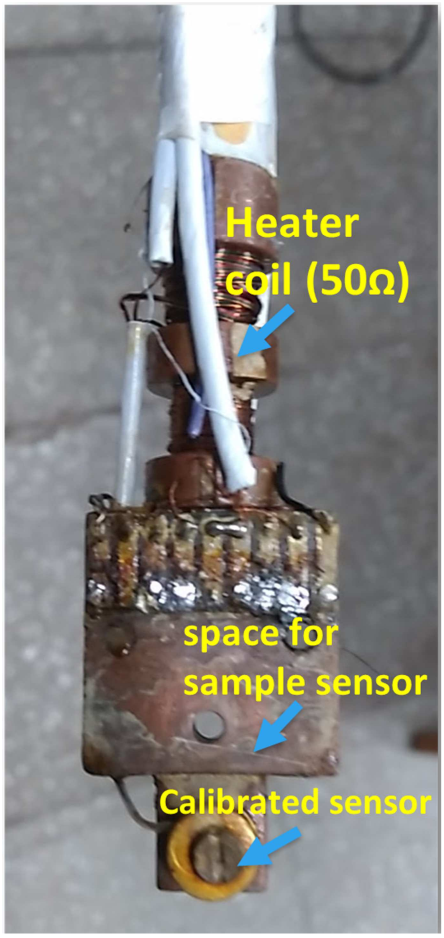

Figure 5. *VTI – Sample Holder.*

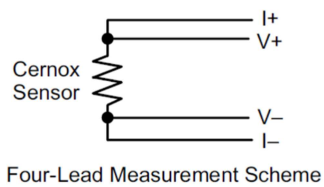

Figure 6. *Four lead measurement scheme of sample and reference sensor.*

Figure 7. *Temperature Controller.*

Using the 4-wire measurement scheme, the current is confined to one pair of current leads with the sensor voltage measured across the voltage leads as mentioned in Figure 6. Electrical leads (4 each from the calibrated and the sample) from these sensors and two leads from the heater coil are taken out using the 10pin connectors. The actual control system is explained as Figure 7.

4. Measurement Algorithms and Data Acquisition System

LabVIEW®, which offers integration with the hardware devices and provides tools for advanced experimental data analysis and data visualization, is used for graphical programming environment. ORIGIN® software is used for plotting the data. Suitable program is developed for the cooldown setup up to 4.7K, reading initial and final temperatures with an increment of 2K and loading the data to a data file until the final temperature of 300K is reached. The communication between the temperature controller and DAQ PC is through General Purpose Instruction BUS (GPIB). The screenshot of the developed block diagram in LabVIEW® is mentioned as Figure 8 and Front panel design of the virtual instrumentation program is mentioned as Figure 9.

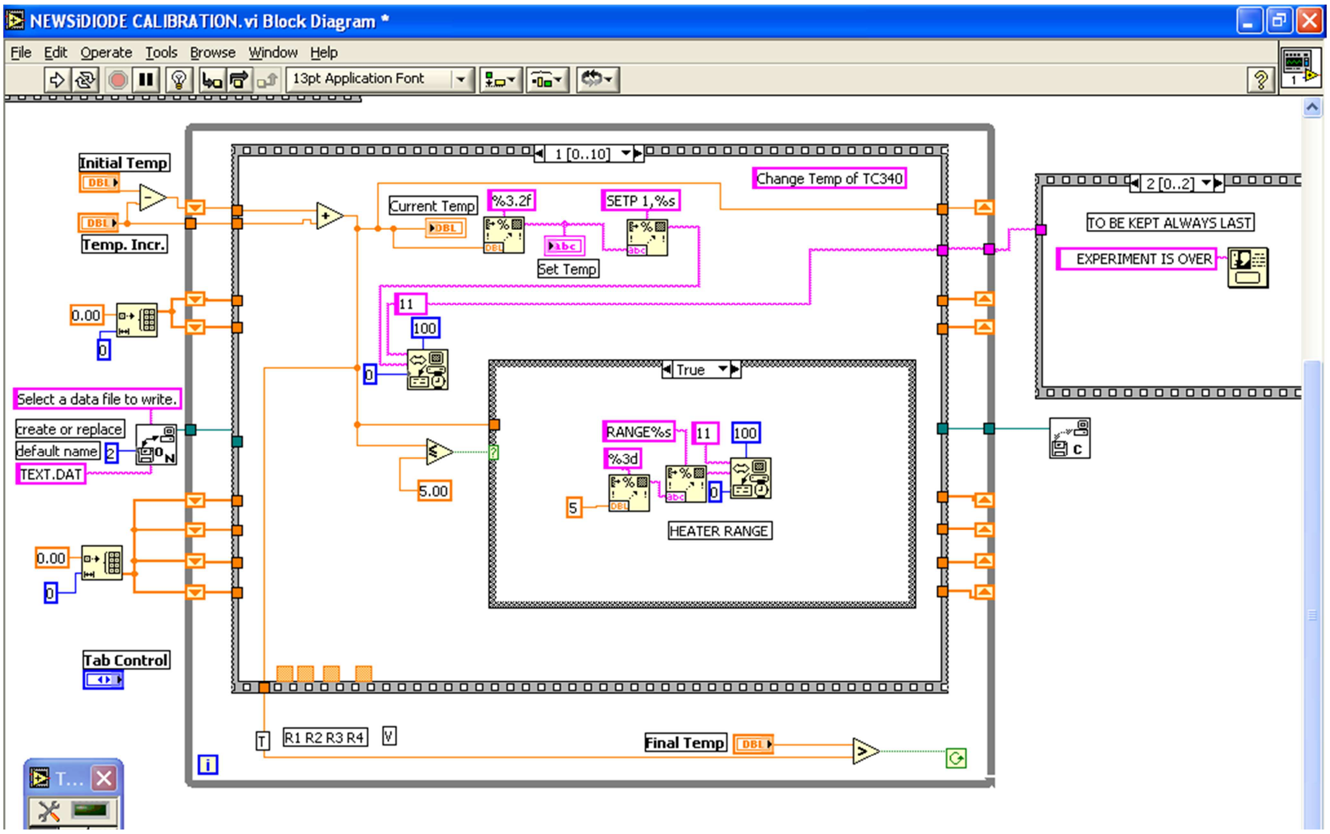

Figure 8. *Screen shot of the (LabVIEW®) block diagram.*

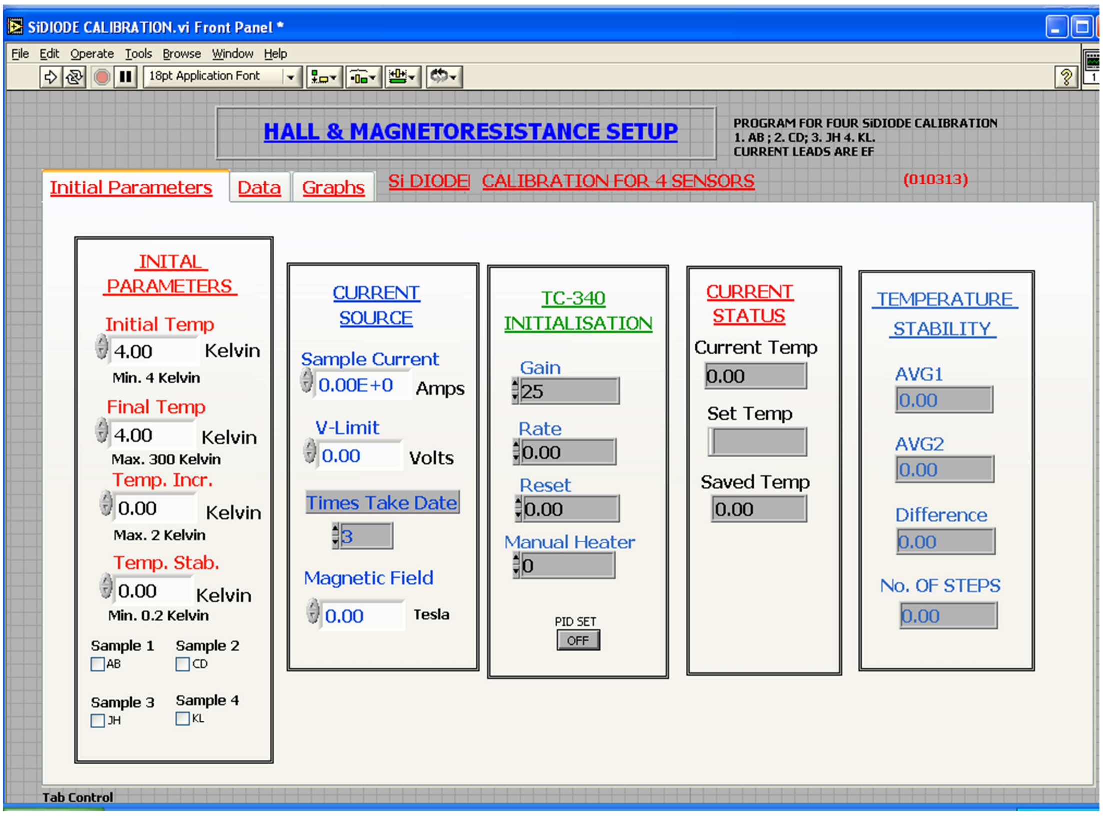

Figure 9. *Front panel design of the virtual instrumentation program.*

5. Calibration of Silicon Diode Temperature Sensors for BARC, Mumbai

The above magnetoresistance setup was used to calibrate a large number of silicon diode temperature sensors for BARC, Mumbai. After inserting the VTI into the helium cryostat, cryostat cooldown program is initiated using the LabVIEW® front panel of virtual instrumentation screen for cooling down up to 4.2 K,. The calibration procedures are executed as per the program by reading the initial temperature (4.2K) until the final temperature of 300K is reached. The read data is stored in a data file. At the final temperature of 300K, the program closes the data file and the readings are exported to ORIGIN® data analysis software for curve plotting and further analysis. Accuracy is a combination of sensor sensitivity and measurement accuracy of the temperature controller. Hence, voltages at various intervals are plotted and calibrated in terms of temperatures. Output data of a typical silicon diode sensor is presented in Table 1 and the same is plotted as a curve and shown in Figure 10. Plots for several such curves are shown in Figure 11. Some of the sensors calibrated are used in the recently developed helium liquefier/refrigerator [2] by BARC as is shown in Figure 12. Here, a couple of sensors is shown mounted on a copper block in the cryogenic piping inside the helium liquefier coldbox.

Table 1. *Output data of a typical silicon diode sensor for BARC applications.*

Temperature (K)	Voltage (V)	Temperature (K)	Voltage (V)	Temperature (K)	Voltage (V)
5.0763	1.59928	33.641	1.09791	62.58	1.0455
6.575	1.5386	35.306	1.09472	64.854	1.04126
8.1367	1.47662	37.398	1.09087	66.627	1.03807
9.7555	1.42149	39.314	1.08745	68.88	1.03393
11.425	1.37569	41.205	1.08415	70.593	1.03072
13.148	1.3378	43.094	1.08087	72.895	1.02645
14.908	1.30196	44.971	1.07758	74.594	1.02318
16.702	1.2684	46.88	1.07426	76.902	1.01876
18.692	1.23315	48.788	1.07084	78.624	1.0154
20.771	1.19646	50.719	1.06737	80.94	1.01088
22.909	1.1519	52.653	1.06387	82.929	1.00701
25.089	1.12249	54.619	1.06016	84.517	1.00379
27.64	1.11204	56.946	1.05596	86.884	0.9991
29.579	1.10677	58.585	1.05292	88.924	0.995
31.48	1.10236	60.812	1.04872	90.851	0.99106

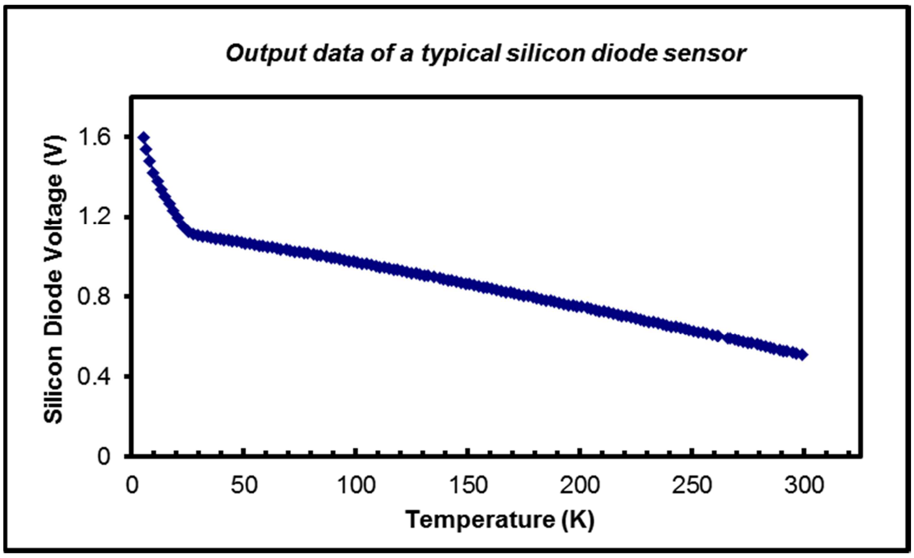

Figure 10. *Calibration curve of a typical silicon diode sensor for BARC applications.*

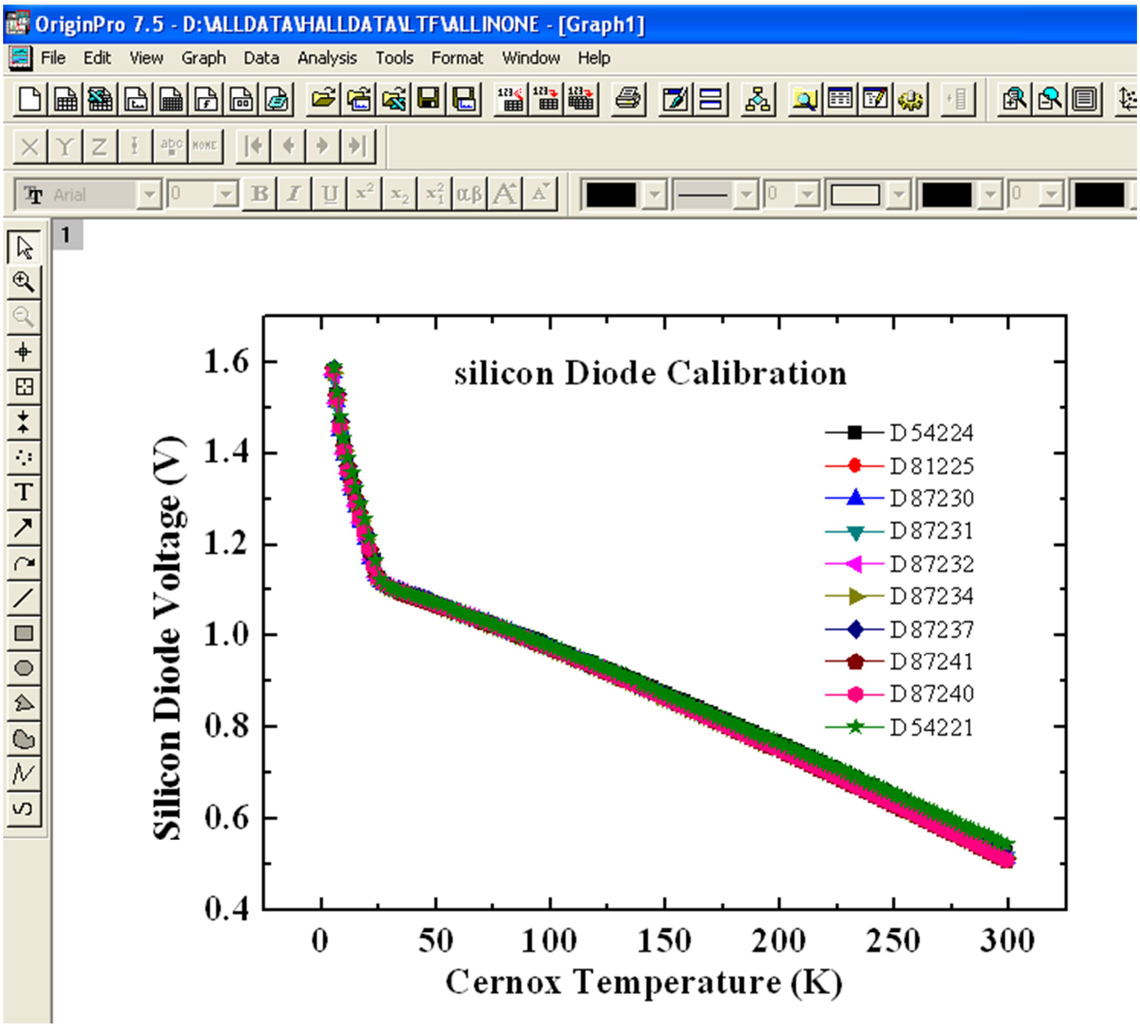

Figure 11. *Calibration curve for several sensors used for BARC applications.*

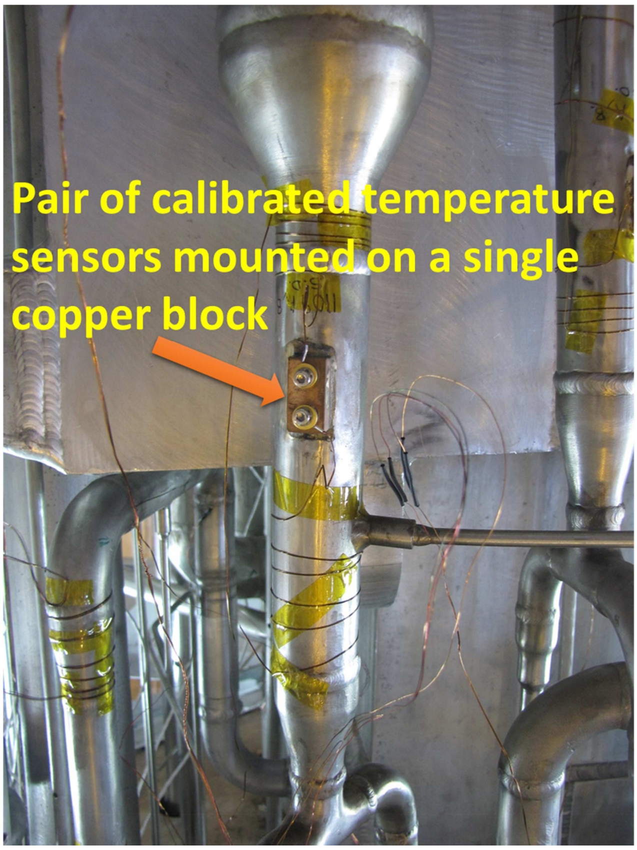

Figure 12. A pair of calibrated temperature sensors mounted on a single copper block on the coldbox piping of the helium liquefier developed by BARC, Mumbai.

6. Conclusions

Using the above described in-house developed, magneto-resistance setup, a large number of sensors for BARC, Mumbai were successfully calibrated at TIFR. Some of these sensors were installed in the newly developed helium liquefaction/refrigeration system of BARC and has been found to be working well. The present setup is proposed to be extended in future to multi-channel temperature calibration, with a plan to calibrate 4 sensors on a single run. Work on the development of a low cost temperature calibration setup for single sensor calibration using a small cryostat of about 5 liters capacity through the modification of a standard liquid helium transport Dewar with custom made VTI, is currently under progress.

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