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KEK Preprint 96-35
June 1996
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Presented at
the 16th International Cryogenic Engineering Conference (ICEC16)/
International Cryogenic Materials Conference (ICMC),
Kitakyushu, Japan, May 20 - 24, 1996.

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Temperature Measurement under High Magnetic Fields around 1.8 K by using CGR Thermometers

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Carbon glass resistance (CGR) thermometers were used for accurate temperature measurement under high magnetic fields around 1.8-1.9 K. For accurate temperature measurement of the LHC (Large Hadron Collider) model magnet, we investigated the magnetoresistance of CGR thermometer up to 9.3 T at around 1.8 K. The magnetoresistance at 4.3 K under magnetic fields of up to 7.7 T was also measured for comparison. At temperature around 1.8 K, the maximum temperature errors of 0.3-0.8 % ($\Delta T/T$) were observed at 4-5 T. At 4.3 K, the temperature errors increased monotonously, and reached -1.5 % at 8 T. Measured data at 1.8 K-1.9 K are compared with predicted curve based on the results obtained by other researchers.

INTRODUCTION

Due to an increase of application of high magnetic fields by using NbTi superconducting magnets, large superfluid helium cooling system is now widely used to cool those magnets at around 1.8 K. For example, the Large Hadron Collider (LHC) project requires to cool several thousands of high field superconducting magnets down to 1.8 K.

The precise temperature measurement of the magnet is one of the essential issues, because almost all kind of low temperature thermometers are affected by the existence of strong magnetic fields. The carbon glass resistance(CGR) thermometer is applicable even under the magnetic fields [1-3]. However, data on magnetoresistance of CGR thermometer at around 1.8-1.9 K are not available.

In order to obtain those data, two CGR thermometers were placed in the bore of the LHC model dipole magnet which can provide the magnetic fields up to about 9 T at 1.8 K. The thermometers were aligned along parallel and perpendicular orientation to magnetic fields in addition to the Hall effect magnetic field sensors. This paper presents the results of the magnetoresistance measurements of the CGR thermometers at 1.8-1.9 K.

EXPERIMENTAL SETUP

A magnetoresistance measurement of CGR thermometers was carried out during the training quench tests of the LHC model magnet. A schematic drawing of the pressurized superfluid helium experimental system is shown in Figure 1. The cryostat is designed for dedicated test of LHC high field superconducting magnet. The magnet is cooled by pressurized superfluid helium in the 1.8 K bath with a capacity of about 500 liters. A details of the system is presented in another paper at this conference [4].

A type of CGR-1-1000 thermometers were placed in a G-10 sensor bar together with the Hall effect magnetic field sensors (BHA-921, Bell). The sensor bar was put into the magnet bore and used for identifying a quench origin. These CGR thermometers were calibrated by the Lakeshore Cryoelectronics in 1991-2. Constant current of 1 μA was supplied by a battery-operated current source (Model 101, Lakeshore cryoelectronics). Figure 2 shows the set up details of two CGR thermometers and Hall sensors in the quench antenna bar.

The magnetoresistance of the CGR thermometer was measured at 4.33 K, 1.89 K and 1.81 K when the magnet was energized for the training quench test. Table 1 lists parameters including temperature, current increasing rate (ramp) and current holding time. A magnet energizing procedure differs from case to case, however, 1.8 K bath temperature was quickly equalized in every case.

Reference temperature was monitored by an another calibrated CGR thermometer placed near the magnet in the 1.8 K bath, but outside of the magnet.

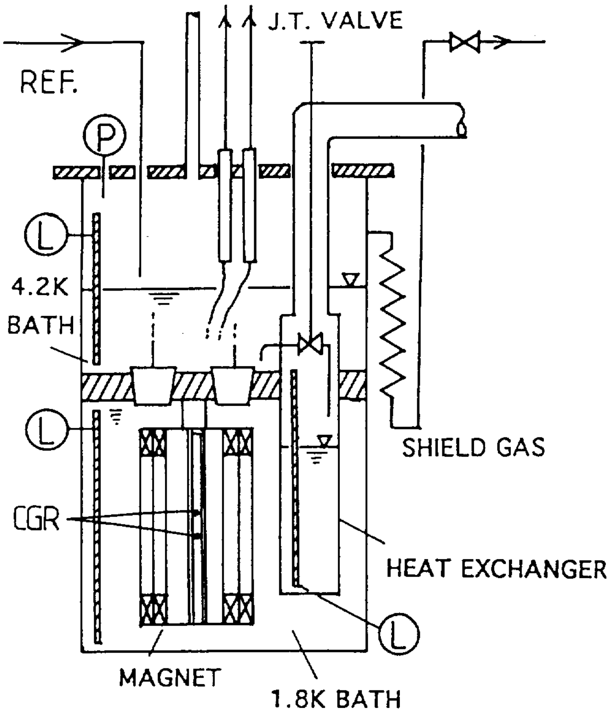

Figure 1 Pressurized superfluid helium system

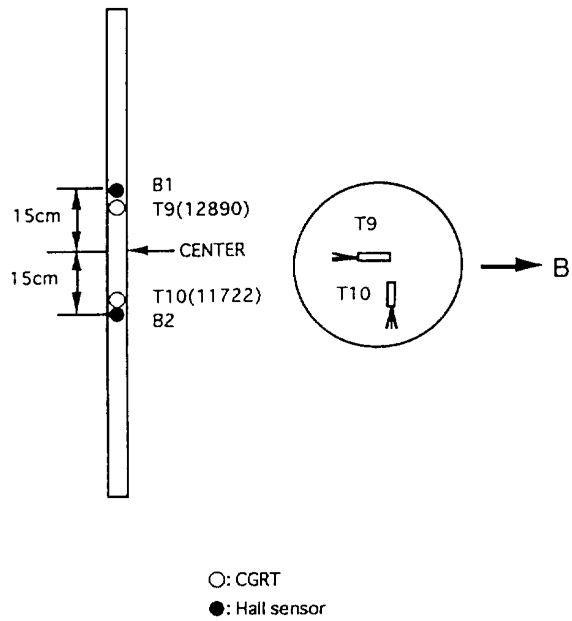

Figure 2 Setting configuration of CGR thermometers and Hall sensors in G-10 sensor bar for measurements

Table 1 Measuring condition

Temperature	Magnetic field	Magnet current ramp condition
4.33 K	0~7.75 T	20 A/s, 5 min. holding at every 2000A step
1.89 K	0~8.97 T	10 A/s, continuously increasing
1.81 K	0~9.33 T	15 A/s, 1 min. holding at every 2000A step

EXPERIMENTAL RESULTS OF MAGNETORESISTANCE OF CGR THERMOMETER

We define a percentage of the magetoresistance as follows:

$$\frac{\Delta R}{R} = \frac{R(T_{ref},B)-R(T_{ref},0)}{R(T_{ref},0)} \text{ X } 100 \ (\%) \qquad (1)$$

where, T_{ref} is reference temperature of 1.8 K helium bath, and $R(T_{ref}, B)$ is the resistance of CGR thermometer at temperature T_{ref} under the magnetic field B in Tesla. Table 2 summarizes the measured data at each temperature. Here, $R_{B//}$ is the resistance of CGR thermometer in parallel magnetic field to the thermometer , and R_{B+} is for the case when magnetic field was perpendicular to the sensor.

Percentage of temperature errors by the magnetoresistance is defined as follows:

$$\frac{\Delta T}{T} = \frac{T[R(T_{ref},B)]-T_{ref}}{T_{ref}} \text{ X } 100 \ (\%) \qquad (2)$$

where, $T[R(T_{ref}, B)]$ is temperature corresponding to the resistance value $R(T_{ref}, B)$ of CGR thermometer.

Parallel magnetoresistance obtained at 1.81 K in this study is inserted in Figure 3 together with already published data[1], for comparison. Our results seem to be consistent with the predicted curve based on the results by previous research.

Table 2 Measured magnetoresistance at various temperature. Magnetic field was measured by a Hall sensor near $R_{B//}$, and the bath temperature fluctuation is less than 2 mK for 1.89 and 1.81 K.

T(K)	B(T)	$R_{B//}$(kΩ)	$dR/R_{//}$(%)	R_{B+}(kΩ)	dR/R_{+}(%)
4.33	0	10.50		11.17	
	1.6	10.54	+0.4	11.22	+0.4
	3.2	10.65	+1.4	11.35	+1.6
	4.8	10.76	+2.5	11.47	+2.7
	6.4	10.88	+3.6	11.62	+4.0
	7.5	10.98	+4.6	11.73	+5.0
1.89	0	68.46		77.24	
	1.6	68.37	-0.1	77.33	+0.1
	3.2	66.59	-2.7	75.31	-2.5
	4.8	66.25	-3.2	75.47	-2.3
	6.4	67.01	-2.1	77.10	-0.2
	8.0	68.78	+0.5	79.62	+3.1
	8.8	69.74	+1.9	80.98	+4.8
1.81	0	88.82		101.1	
	1.6	87.79	-1.2	100.2	-0.8
	3.2	84.95	-4.4	97.50	-3.5
	4.8	84.37	-5.0	97.40	-3.6
	6.4	85.46	-3.8	99.16	-1.9
	7.9	87.42	-1.6	102.3	+1.2
	8.7	88.55	-0.3	103.9	+2.8

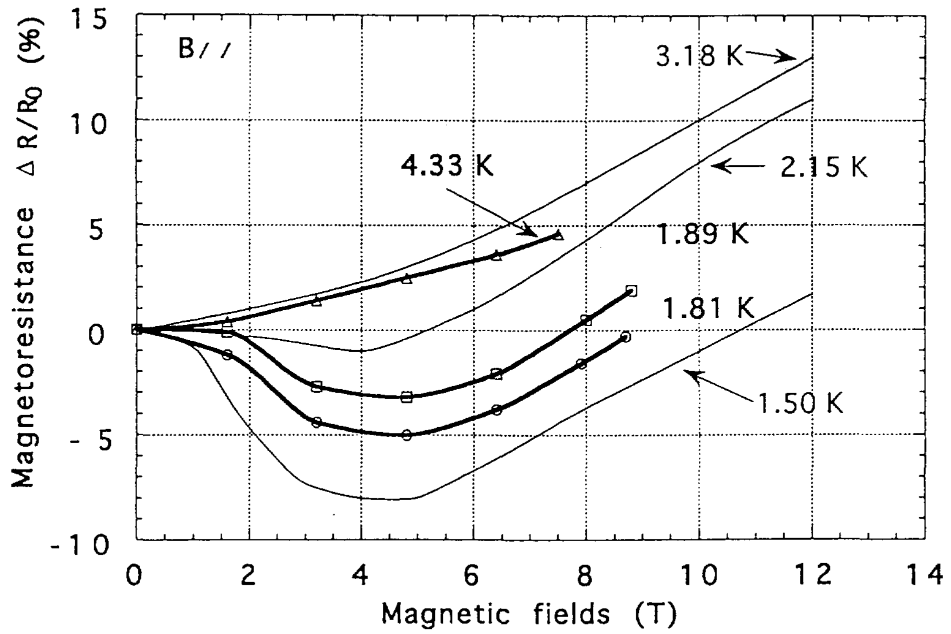

Figure 3 Obtained data at 1.81 K is superimposed on published data [1]

Figure 4 shows the temperature errors in %, due to the magnetoresistance and the orientation dependence of CGR thermometer at three different temperatures. At 4.33 K, the temperature error increases monotonically as the magnetic fields increase and it exceeds -1.5 % at 8 T. A very little orientation dependence was observed at this temperature. At 1.89 and 1.81 K, the temperature errors have peak values near 4-5 T. Concerning field orientation dependence of the magnetoresistance, perpendicular fields affect slightly more on magnetoresistance than parallel fields. These features of the magnetoresistance of the CGR thermometer qualitatively agree with the already published data [1-3].

Figure 5 shows the temperature errors in mK to the magnetic fields change at three temperatures. Only the results for perpendicular field is shown here. At around 1.8 K, CGR thermometer can be used for temperature measurement with temperature errors of about ±12 mK under the magnetic fields up to 9 T.

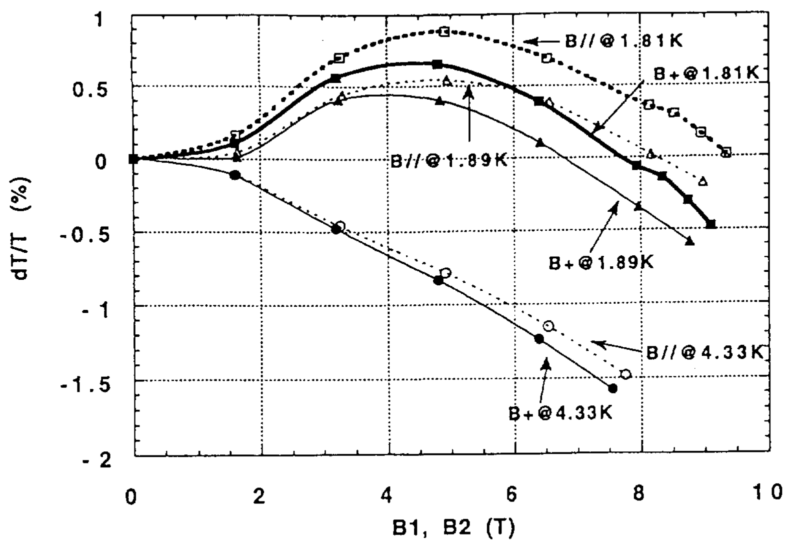

Figure 4 Temperature errors in % vs. magnetic fields applied in parallel and perpendicular at 4.33 K, 1.89 K and 1.81 K.

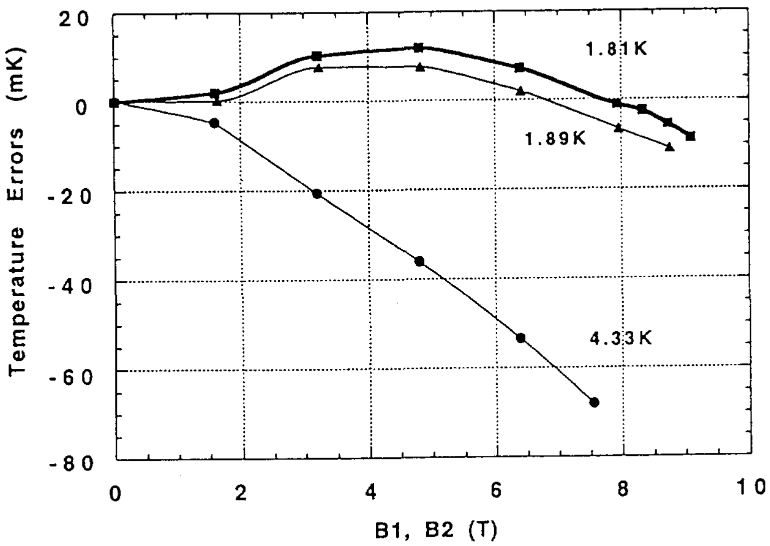

Figure 5 Temperature errors in mK vs. perpendicular magnetic fields at 4.33 K, 1.89 K and 1.81 K

SUMMARY

The magnetoresistance of the CGR thermometer at around 1.8 K is measured first time. For accurate temperature measurement at around 1.8 K under the high magnetic fields up to 9 T, the magnetoresistance of the CGR thermometer was investigated for perpendicular and parallel magnetic fields orientation to the CGR thermometer. For the magnetic field range of 0-9 T, temperature errors due to the magnetoresistance were within ±12 mK, indicating positive peak at around 4-5 T. In these temperature ranges, as small difference as 10 mK was observed between two fields orientation. The data obtained in this study are consistent with the expectation based on previous data [1].

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