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Cryogenic technology for tracking detectors

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RD39 Collaboration

Abstract

A low-mass cryogenic cooling technique for silicon sensor modules has been developed in the framework of the RD39 Collaboration at CERN. A prototype low-mass beam tracker cryostat has been designed, constructed and tested for applications in fixed target experiments. We shall report here briefly the main features and results of the system. © 2001 Elsevier Science B.V. All rights reserved.

1. Introduction

In most high-energy physics experiments, the study of particle trajectories is of prime interest. In these experiments there is a strict requirement that the multiple Coulomb scattering of the beam on

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the tracker instrumentation be as low as possible. It is therefore essential to use lightweight construction, built of low-Z materials chosen specifically also for their thermal and mechanical properties so that a mechanically stable and precise tracker is obtained.

The aim of the RD39 Collaboration was to build a cryogenic detector system for studying the properties of silicon detectors (the Lazarus effect) [1,2] at low temperatures.

2. The low-mass cryostat

The cooling system developed at CERN consists of a continuous-flow LN_2 open-cycle cryostat constructed for use in a foam-isolated chamber (Fig. 1). The novelty of this system lies in special "cryogenic modules" (Fig. 2) and in the extremely light and thermally isolating material used to make the cryostat.

The cryostat is composed of a rigid box made of 30 mm thick polyurethane foam (Alporit). This material has an effective thermal conductivity of 0.024 W/Km at ambient temperature and a density of 30 kg/m^3. The box has inner dimensions of $94 \times 140 \times 370\,mm^3$ and a cold volume of about 4000 cm^3. The Alporit sheets are covered on each side by a 50 μm thick sheet of aluminum, which prevents the diffusion of water into the foam.

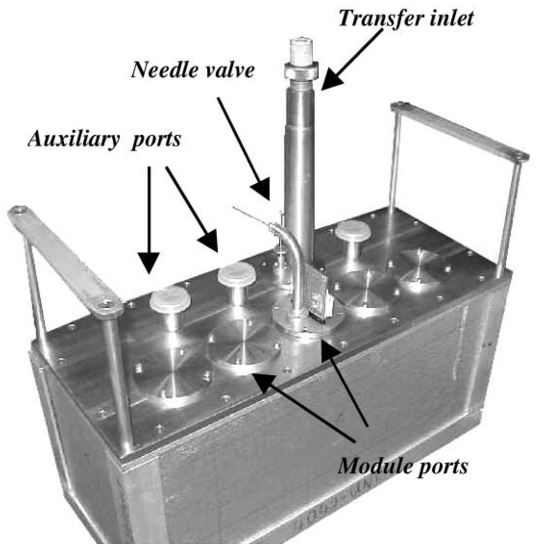

Fig. 1. The low-mass cryostat has several access ports. Five ports are to insert the cryogenic modules, one port is for the inlet of the LN_2 transfer line, and three additional ports are for instrumentation connections. A needle valve allows the liquid to refill the box.

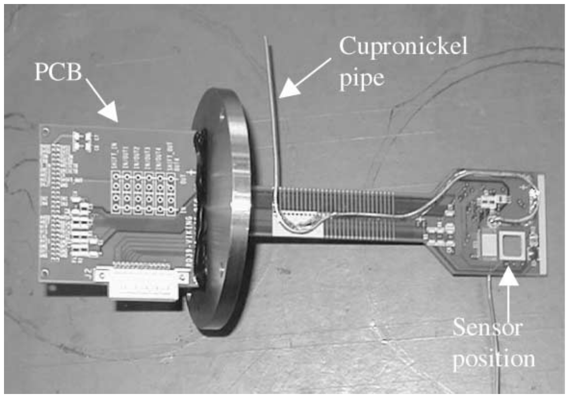

Fig. 2. Picture of a cryogenic module: a thin cupronickel pipe is soldered on the PCB. A flow of cold nitrogen gas in the pipe cools down the module.

The silicon detectors are mounted on cryogenic glass-epoxy-printed circuit board (PCB). The PCB is inserted through a slot in a stainless-steel flange and glued in place.

The cooling is achieved with a continuous two-phase flow of nitrogen through a thin-wall cupronickel (70% Cu/30% Ni) capillary pipe (1 mm inner diameter) soldered on the PCB.

A flow meter and a manual valve control the gas flow rate. By setting the flow rate in the pipe, it is possible to adjust the temperature of the detector between $\sim$80 and 300 K. In the higher end of this range only gas flows through the capillary pipe.

Measurements of the thermal stability and cooling power of the system were done. Two resistors of 100 Ω were used to simulate the power dissipated by the read-out chip. The temperature stability has been studied for different values of dissipated power applied. A Pt100 platinum resistance thermometer was soldered onto each PCB close to the detector for the measurement of the temperature. A LabVIEW program collected data on the time evolution of the temperature.

Table 1
Minimum temperature values and corresponding gas flow rate for four values of applied power. No liquid subcooling is used

Power (Watt)	Minimum temperature (K)	Gas flow rate (Nl/h)
0	106	100
1	111	150
2	124	150
3	131	170

The measurements show that it is quite easy to stabilize temperature by controlling the output gas flow rate. Table 1 shows the values of the minimum temperature measured for four values of dissipated power applied. It also shows the smallest gas flow rate needed to cool down at the minimum temperatures.

The cryostat can operate at lower temperatures (~ 80 K) by a two-phase flow of nitrogen through the capillary pipes integrated in the modules. Inside the foam chamber an open copper reservoir can be refilled with liquid nitrogen by opening the needle valve. The two-phase flow in the capillary pipe is guaranteed by liquid subcooling.

For higher temperatures no liquid is required in the reservoir. The needle valve is almost closed so that a permanent flow of dry cold nitrogen at a slight overpressure prevents back-diffusion of humid ambient air into the box.

3. Conclusions

A first prototype low-mass cryogenic system has been produced for application in high-radiation environments. The system has the advantages of working at any temperature between ~ 80 and 300 K with a low consumption of LN_2, achieved by using a commercial low-loss vapour-cooled LN_2 transfer line.

The system was designed to be manageable and flexible. Up to 5 modules can be cooled concurrently and independently. The modules can be easily extracted from the foam box if the detectors needed to be replaced.

References

[1] RD39 Collaboration, K.Borer et al., Nucl. Instr. and Meth. A 440 (2000) 5.
[2] RD39 Collaboration, K.Borer et al., Nucl. Instr. and Meth. A 440 (2000) 17.