EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH
European Laboratory for Particle Physics

Large Hadron Collider Project

LHC Project Report 230

Cryogenic R&D at the CERN Central Cryogenic Laboratory

M. Blin, G. Ferlin, P. Gauss, C. Policella, J.-M. Rieubland, G. Vandoni

Abstract

The Central Cryogenic Laboratory operates since many years at CERN in the framework of cryogenic R&D for accelerators and experiments. The laboratory hosts several experimental posts for small cryogenic tests, all implemented with pumping facility for GHe and vacuum, and is equipped with a He liquefier producing $6 \cdot 10^5$ l/year, which is distributed in dewars. Tests include thermomechanical qualification of structural materials, cryogenic and vacuum qualification of prototypes, evaluation of thermal losses of components. Some of the most relevant results obtained at the laboratory in the last years are outlined in this paper.

* LHC Division

Presented at ICEC 17, 14-17 July 1998, Bournemouth, UK

Administrative Secretariat
LHC Division
CERN
CH - 1211 Geneva 23
Switzerland

Geneva, 25 August 1998

Cryogenic R&D at the CERN Central Cryogenic Laboratory

M. Blin, G. Ferlin, P. Gauss, C. Policella, J.-M. Rieubland, G. Vandoni

CERN - LHC Division, CH - 1211 Geneva 23, Switzerland

The Central Cryogenic Laboratory operates since many years at CERN in the framework of cryogenic R&D for accelerators and experiments. The laboratory hosts several experimental posts for small cryogenic tests, all implemented with pumping facility for GHe and vacuum, and is equipped with a He liquefier producing $6 \cdot 10^5$ l/year, which is distributed in dewars. Tests include thermomechanical qualification of structural materials, cryogenic and vacuum qualification of prototypes, evaluation of thermal losses of components. Some of the most relevant results obtained at the laboratory in the last years are outlined in this paper.

1 INTRODUCTION

Cryogenics for accelerators at CERN is an ever expanding area, following the outreaching development of superconductor technology, which is applied for the accelerating resonating cavities as well as for the superconducting orbit-bending and focusing magnets. Development and preparatory work in view of the construction of the Large Hadron Collider (LHC) and of its experiments is under way [1], still the requirements in cryogenics for the already running accelerator complex are not completely achieved. In this framework operates the Central Cryogenic Laboratory (Cryolab), fulfilling the necessity of a small and flexible structure for carrying out tests in cryogenic environment.

Associated to the laboratory, a helium liquefier produces 70 l/h helium, which is delivered to the 20 working posts with mobile dewars of 500 l. The posts are supplied with pumping refrigeration up to a maximum of 3 W at 1.8 K per post by a pipe network, the total refrigeration capacity at 1.8 K amounting to 10 W. A dedicated data acquisition system has been developed and realized in 4 specimen, processing the control and acquisition signals with a personal computer, under LabVIEW 4.1.

Machining of cryostat and cryogenic circuit components is performed in an internal mechanical workshop. The laboratory is further equipped with a gas chromatograph with flame ionization detection and a tensile testing machine, allowing operation between 1.8 K and 500 K for a uniaxial stress ranging from 40 kN to 100 kN.

About 25 different tests are performed yearly in the laboratory, including component qualification, materials characterization, quality assessment of prototypes. Owing to its miscellaneous activities, the Cryolab is ideally suited to host training and collaborate in education of young technicians and scientists. On the average, 3 students per year are formed to cryogenic skills, and courses are regularly held in the laboratory rooms, which contributes also in this way to the advancement in cryogenic technology.

2 RELEVANT RESULTS

2.1 Thermal properties

The majority of the tests performed at the Cryolab focus on thermal properties of materials or components at low temperature. Amongst these, most of the tests which are performed in the framework of the LHC project concern the evaluation of heat fluxes from components to heat exchangers. The thermodynamic cost of refrigeration below 2 K imposes that the heat loads at this temperature are kept to a minimum, by temperature staging between 300 K and 1.9 K and insulation. All the components inside a cryostat are therefore designed to minimize the heat fluxes, especially at 1.9 K. Some of the methods applied to the measurement of heat loads will be described hereafter.

A calibrated heatmeter [2] consists in a thermal impedance, which dimensions are adapted to the desired heat flux range and temperature level. Above 2 K, heatmeters rely on bulk thermal conduction, below 2K the impedance is obtained by the Kapitza effect.

Applications of heatmeters include the evaluation of the optimal thermomechanical design for the insulating support columns of the dipole cold mass [3], which minimizes the heat loads induced at the cold mass (1.9 K), radiative shield (5-20 K) and thermal shield (50-75 K) of the LHC magnet cryostat. Also, the heat load of two types of thermal insulators [4-5], which might be applied between the cold mass and the radiative screen to avoid a contact between them, is measured as a function of compressive load for boundary temperatures between 2 K and 5-30 K.

A Kapitza effect based heatmeter has been applied to evaluate the thermal performance of a quench relief valve prototype for the LHC cold mass [6]. In normal operation, the poppet is helium tight for both hydraulic and thermal separation of the cold mass and the recovery header.

However, heatmeters are not the only technique applied to measure heat fluxes. Besides the main dipole magnets, the LHC will need some 800 superconducting corrector magnets, powered individually by current leads operating between 300 K and 1.8 K. A study aimed at evaluating the possibility of minimizing the heat loads by a high T_c superconducting cold element (BSCCO) and a warm copper part, with contact thermalization cooling. The heat loads at 1.8 K are obtained by measuring the temperature drift of the saturated HeII bath once the pumping is switched off ("thermal drift method") [7]. The thermal losses at 50K, 20K and 1.9K of fully resistive leads are also currently measured: at 1.9 K, a Kapitza heatmeter is used, while at 50 K and 20 K, the heat flow is measured by enthalpy balance across a heat exchanger.

A part of the series production of dipole magnets will be tested in the next years; the magnetic measurements require instrumentation working at 300 K, applying an anticryostat installed inside the cold apertures of the dipoles (cold bores). Radiative shielding is ensured by a floating stainless steel screen. To reduce the heat load, the screen can be aluminum coated. The emissivity reduction obtained by this has been measured by electrically heating the screen to reach steady state conditions, the radiative heat loss to the surrounding bath being exactly compensated by the electrical power which is necessary to maintain a constant temperature.

In spite of the tests on single components, the evaluation of the complete budget of heat loads to the cryomagnets makes measurements on a full scale cryostat model unavoidable. A dedicated Cryostat Thermal Model (CTM) was therefore realized, containing all the elements belonging to the real cryostat, as well as a dummy cold mass [8]. Heat loads under nominal LHC working conditions are evaluated by enthalpy balance. Following the evolution of the LHC dipole cryostat design, subsequent versions of the CTM have succeded (see [9]).

Thermal measurements are not exclusively limited to heat load evaluations; as an example, the LHC cold mass heat exchanger has been studied in order to determine the separate contribution of the Kapitza resistance and copper bulk thermal resistance to the heat exchange. The study is presented on this conference [10]. A test-bench for measuring the thermal conductivity of insulating samples has been applied to determine the conductivity of fiberglass, plastics and carbon fiber samples. The test cell contains a cold source, in thermal contact with a reference coolant (LHe, LN_2, water, oil), and a heated element, whose temperature is measured in steady state conditions. The heat flow is given by the applied electrical power, the temperature difference is measured with carbon resistor sensors or a differential thermocouple.

2.2 Material properties

Measurements at cryogenic temperature are performed to characterize mechanical, electrical or magnetical properties of materials and devices. The tensile testing machine has been applied to determine the resistance to uniaxial stress of samples of the welding seam of the magnet yoke, at 4.2 K, with an applied force of 100 kN. A further application, at cryogenic temperature, consisted in the measurement of the resistance to stress cycling at 4.2 K of some 100 samples of stainless steel and aluminum collars for the LHC magnets, with a maximal applied force of 40 kN and 100 kN [11]. Tensile stress measurements have also been performed on carbon fiber and glass fiber samples at 1.8 K, with a maximal applied stress of 40 kN.

The electrical resistivity of materials can be measured between 1.8 K and 300 K with a precision of 10^{-7} Ohm in a dedicated set-up. A further test-bench is dedicated to measure thermal contraction occurring between 300 K and 77 K; in principle, it is possible to operate it at LHe as well. The measurement is done with an inductive sensor, fixed at a reference quartz sample of 50 mm length. A comparison of the thermal contraction between 300 K and 77 K of samples of different austenitic stainless steels for the magnet collars has been performed.

The thermoelectric parameters of BiSb alloys have been studied between 1.8 K and 70 K [12]. The study aimed at comparing how distinct growth techniques applied to produce the crystals affected the thermoelectric properties.

The yield strength and Young module, at liquid helium temperatures, can be measured in a test-bench, developed to test various austenitic stainless steels for the LHC welded by MIG, TIG, EB and laser. Two facilities are now operational, one reaching a maximum force of 25 kN, the other of 5 kN; the strain rate varies between 3.10^{-4} to 10 s^{-3}. The elongation of the specimens is measured directly on the samples, inside the cryostat, with two LVDT sensors, to eliminate the effects of bending by averaging of the two signals. The accuracy of the elongation measurement amounts to 0.1 μm [14], for sample sizes from 1 mm^2 to 6 mm^2.

2.3 Qualification of cryogenic devices

In the framework of R&D for the LHC project, as well as for quality assessment purposes, prototypes of cryogenic devices are studied in nominal operating conditions and in the security limit of the relevant external parameters. A prototype of a safety quench relief valve, already cited, was leak tested in nominal conditions for different actuator pressures over the poppet [6]. Fatigue tests are performed on stainless steel bellows, in pressurized LN_2 or LHe, to assess the optimum design and material. Cryogenic tight high voltage feedthroughs are tested in pressurized liquid helium at 1.9 K. Leak measurements are as well performed on cryogenic joints and flanges at 4.2 K and 1.8 K, under a pressure of 20 bar.

R&D is a still ongoing process for the future experiments of the LHC. A prototype Ar discharge valve for the ATLAS experiment has been thermally and mechanically cycled and leak tested for different actuator pressures, in liquid nitrogen.

2.4 Other activities

Besides the cryogenic tests, the Cryolab contributes to R&D at CERN by advisory activity, design of cryostats and cryogenic test benches, set-up of measuring procedures and calibration of sensors.

A microcryostat of 30 cc of HeII, for calorimetric beam position monitors [13], has been designed, constructed and tested in working conditions. Its essential features are presented at this conference .

Calibration of carbon resistor temperature sensors, for internal use and upon request from other LHC groups is performed on a dedicated working post; around 300 sensors are calibrated yearly, half of which are then mounted inside the cryostats of the laboratory. Capacitive force transducers, developed and used to monitor the coil pre-stress during assembly of dipole models for LHC are calibrated under uniaxial tension at 300K, 77K and 4.2K in the tensile testing facility.

With the help of the chemical analysis laboratory, a study aimed at characterizing the gaseous impurities released by the LHC cold masses has been carried on, on some of the 10 m dipole prototypes. Sampling at 300 K by purge-and-trap, accumulation in selective adsorbent filters and analysis by mass spectroscopy have permitted to quantify the moisture degassing from the cold masses and to identify in solvents, sulfates, and hydrocarbon chains the main volatile chemical impurities.

ACKNOWLEDGMENTS
Many of the achievements obtained at the Cryolab would not have been possible without the active contribution of H. Bouyaya, J.-C. Carrère, S. Chevassus, M. Cugnet, C. Delpech, S. Guido, L. Le Mao, M. Pangallo, A. Vergé, H. Vigier.

3 REFERENCES

[1] Bremer, J., Dauvergne, J.-P., Delikaris, D., Delruelle, N., Haug, F., Kesseler, G., Passardi, G., Rieubland, J.-M., Tischhauser, J., Cryogenics for CERN experiments: past, present and future, ICEC16 Kitakyushu, Japan, 20-24 May 1996, Proceedings
[2] Ferlin, G., Jenninger, B., Rieubland, J.-M. Precise wide range heatmeters for 1.5 K up to 80 K, subm. to: CEC/ICMC'97 Portland OR, 27 July-1 Aug 1997
[3] Mathieu, M., Parma, V., Renaglia, T., Rohmig, P. and Williams, L.R., 293 K- 1.9 K supporting systems for the Large Hadron Collider (LHC) cryo-magnets, subm. to CEC/ICMC'97 Portland OR, 27 July-1 Aug 1997
[4] Jenninger, B., Peon, G., Szeless, B., Characterization of net type thermal insulators at 1.8 K low boundary temperature, Cryogenics (1998) 38 25
[5] Darve, C., Vandoni, G., Thermal performance of insulating cryogenic pin spacers, subm. to: ICEC17, Bournemouth 14-17 July 1998
[6] Danielsson, H., Ferlin, G., Jenninger, B., Luguet, C., Milner, S.E., Rieubland, J.-M., Cryogenic performance of a superfluid helium relief valve for the LHC superconducting magnet, Adv. Cryo. Eng. (1996) 41 805
[7] Ballarino, A., Ijspeert, A., Design and test of the prototype high T_c current leads for the Large Hadron Collider orbit correctors, IEEE Trans. Appl. Supercond. (1995) 5 805
[8] Dufay, L., Ferlin, G., Lebrun, P., Riddone, G., Rieubland, J.-M., Rijllart, A., Szeless, B., Williams, L.R., A full-scale thermal model of a prototype dipole cryomagnet for the CERN LHC project, Cryogenics (1994) 34 693
[9] Darve, C., Parma, V., Williams, L.R., Measurement and analysis of the thermal performance of the second series of LHC prototype dipole magnet cryostats, submitted to ICEC17, Bournemouth, 14-17 July 1998
[10] Camacho, D., Policella, C., Chevassus, S., Rieubland, J.-M., Vandoni, G., van Weelderen, R., Thermal Behavior of the HeII LHC heat exchanger, subm. to: ICEC17, Bournemouth 14-17 July 1998
[11] Galante, N., Gilquin, J., Patti, G., Perin, R., Perini, D., Measurement of the resistance to stress cycling at 4.2K of LHC dipole collars, Proceedings R B Goldfarb IEEE Trans. Magn. (1994) 30 1754
[12] Roche, C., Caractérisation d'alliages de bismuth-antimoine à basses températures, Ecole des Mines de Nancy, Rapport de diplome 1997
[13] Bouyaya, A., Policella, C., Rieubland, J.-M., Vandoni, G., Microcryostat for a LHC beam loss monitor based on calorimetry, submitted to ICEC17, Bournemouth, 14-17 July 1998
[14] Jenninger, B., Cryostat and Extensiometer for tensile tests on small specimen at 4.2 K, AT-CR Group Report 01-95