EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH
European Laboratory for Particle Physics

Large Hadron Collider Project

LHC Project Report 614

THE CRYOGENIC SYSTEM FOR THE LHC TEST STRING 2: DESIGN, COMMISSIONING AND OPERATION

E. Blanco, C. Calzas, J. Casas-Cubillos, D. Chanat, P. Gomes, S. Knoops,
M. Sanmarti, L. Serio and A. Suraci

Abstract

A 107-m long superconducting magnet string representing a full-cell of the LHC machine was designed for assembly and commissioning at CERN in order to validate the final design choices. This new facility, thereafter called Test String 2, and its cryogenic infrastructure cons ist of feed and return boxes coupled via transfer lines to a 6 kW @ 4.5 K refrigerator and to a low pressure pumping group, a separate cryogenic distribution line, an electrical feed box with HTS current leads, 2 quadrupole and 6 dipole prototype and pre-series superconducting magnets.

LHC Division

Presented at the 19th International Cryogenic Engineering Conference (ICEC 19)
22-26 July 2002, Grenoble, France

Administrative Secretariat
LHC Division
CERN
CH - 1211 Geneva 23
Switzerland

Geneva, 15 November 2002

The cryogenic system for the LHC Test String 2: design, commissioning and operation

Blanco E., Calzas C., Casas J., Chanat D., Gomes P., Knoops S., Sanmarti M., Serio L., Suraci A.

LHC Division, CERN, 1211 Geneva 23, Switzerland

A 107-m long superconducting magnet string representing a full-cell of the LHC machine was designed for assembly and commissioning at CERN in order to validate the final design choices. This new facility, thereafter called Test String 2, and its cryogenic infrastructure consist of feed and return boxes coupled via transfer lines to a 6 kW @ 4.5 K refrigerator and to a low pressure pumping group, a separate cryogenic distribution line, an electrical feed box with HTS current leads, 2 quadrupole and 6 dipole prototype and pre-series superconducting magnets.

INTRODUCTION

A major milestone in preparation of the construction, commissioning and operation of the Large Hadron Collider (LHC) is the assembly, commissioning and operation of a full-scale model representing a full-cell of the machine lattice, corresponding to the length of the elementary cooling loops.

A first version of this full-scale model, the Test String 1, was assembled, operated and extensively tested between 1994 and 1999 [1]. Some cryogenic components were validated, other modified or re-designed and the overall cryogenic distribution scheme was simplified to increase the reliability and decrease investment and operational costs [2]. Following the successful results of the first operational model, a new full-cell, the Test String 2, has been designed, assembled and commissioned. In its first phase at the end of 2001, it was composed of 2 quadrupoles and 3 dipoles. During the 2001/2002 winter shutdown 3 pre-series dipoles were added to make the 107-m full length. The design makes use of the existing infrastructures and facilities in the SM18 cryogenic test area [3] and incorporates all modifications and simplifications suggested by the testing of its predecessor.

SYSTEM LAYOUT

The cryogenic system of the Test String 2 (Figure 1) is composed of: the superconducting magnets string with the superfluid helium bayonet heat exchanger, the cryogenic distribution line (QRL) and the electrical feed box (DFB) to allow powering. Other components such as the feed and return boxes, the quench buffer vessel (QBV), the refrigerator and ancillary systems are peculiar of the Test String 2 although components with similar functions will be installed in each sector of the LHC machine. An existing 6 kW refrigerator provides the cooling power needed for the Test String 2 components. It is boosted with a liquid nitrogen precooler unit to reduce the cooldown time and ensure sufficient liquefaction capacity. The helium supply and recovery are performed via three vacuum insulated and thermally shielded transfer lines, extending over a length of about 35 m between the Test String 2, the refrigerator and the low pressure pumping group.

The cryogenic feed box (CFB) is an interconnection module between the transfer lines coming from the refrigerator and the QRL. It includes a jumper connection to provide and recover helium at 4.5 K and 20 K from the DFB. It consists of instrumentation and valves to distribute cooling power to the various circuits and retrieve gaseous helium back to the refrigerator and the low pressure pumping group. The CFB houses safety relief devices for all circuits of the QRL and the transfer lines. It is connected to the servicing manifold for conditioning of circuits prior to cooldown.

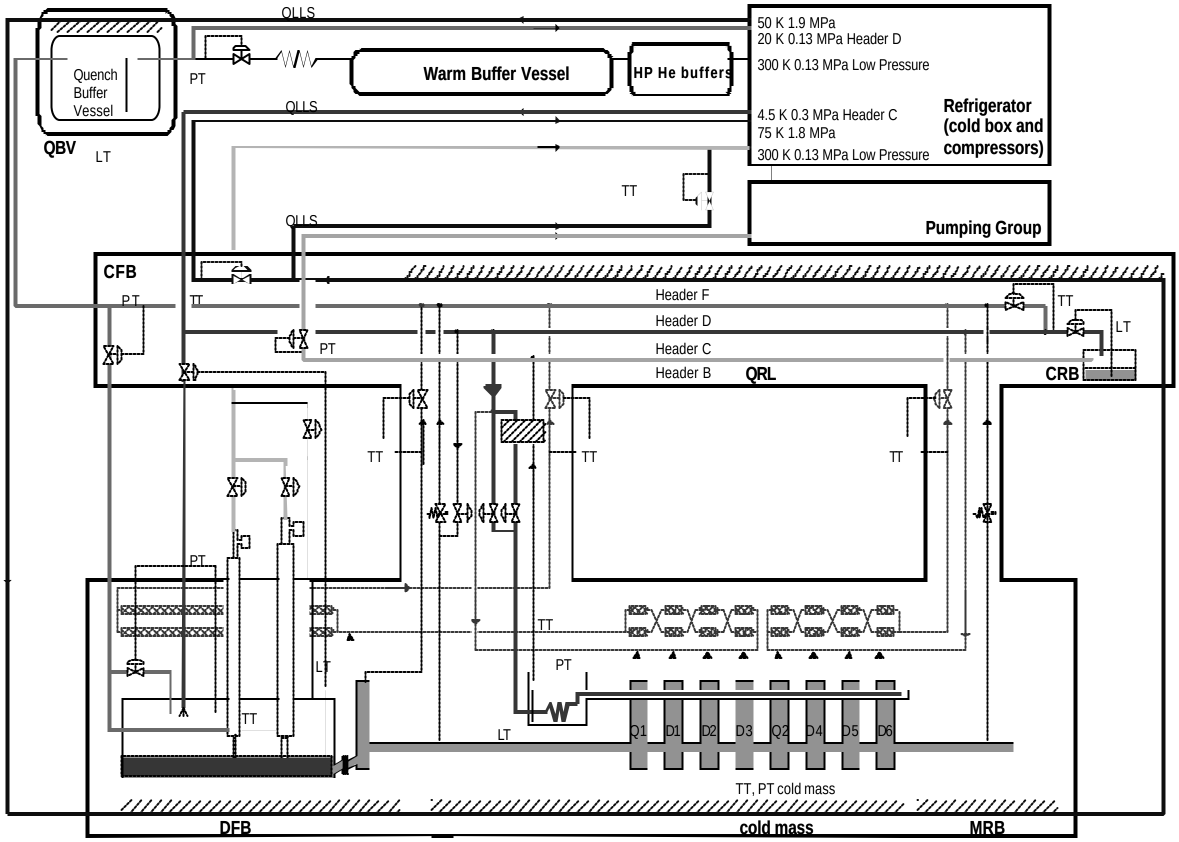

Figure 1 Simplified flow-scheme of the LHC Test String 2

The cryogenic distribution line [4] is the first test cell extensively tested at CERN [5]. As for its final configuration in the LHC machine it contains all cryogenic headers to distribute cooling power along the Test String 2. It consists of two service modules and in between straight pipe elements of transportable length with the inner and outer bellows systems.

The first service module feeds the superfluid helium loop via a very low pressure heat exchanger and two J-T valves, the beam screen cooling loop, the DFB shuffling module and the magnet cold mass. The second service module feeds the second half-cell beam screen cooling loop and recovers helium from the cold mass during cooldown. Two prototype quench relief valves, one at each end of the magnet string in their respective service modules, protect the cold mass from overpressure by opening as pressure actuated safety relief devices at a set pressure of 18 bar.

The electrical distribution feed box houses the HTS current leads to power the Test String 2 magnets [6]. The DFB mechanically supports the current leads, distributes the power via the bus-bars and provides the necessary cooling (4.5 K liquid helium and 20 K gaseous helium flow) to maintain the current leads in the superconducting state. It is connected to the magnet string via a lambda plate followed by a shuffling box where the bus-bars are re-positioned to feed the magnets. Liquid helium vaporized in the DFB helium vessel is collected, via a pressure control valve, into the 20 K supply for cooling the resistive part of the leads. This cooling flow exits the current leads at ambient temperature and is controlled by warm valves to maintain the HTS of each lead at its operating conditions (i.e. between 4.5 K liquid helium and 50 K). Six 13 kA leads supply the three main magnets circuits and twenty-eight 600 A leads feed twelve circuits for magnets correctors and auxiliary bus bars.

The superconducting magnets operate in a bath of pressurized superfluid helium at 1.9 K and 1 bar. A total inventory of 2200 litres of superfluid helium is contained in the cold mass. It is employed both as a conductive medium for heat extraction via a bayonet heat exchanger and as a thermal buffer during transient phases.

The bayonet heat exchanger [7] is a 54-mm inner diameter, 2 mm thick wall, cylindrical tube made of cold-worked OFHC copper and running inside the cold mass. It is fed via an inner tube that deposits saturated superfluid helium at the far extremity of the magnets string. The flowing superfluid helium is evaporated along the heat exchanger length. Because of the high thermal conductivity of the pressurized bath, the wetting length of the heat exchanger depends on the heat loads and the cold mass temperature set point. The temperature of the saturated helium is maintained below the magnet temperature by continuous pumping via the very low pressure heat exchanger. Two supercritical helium loops (5 K and 3 bar) provide cooling for the cold support post and the beam screens.

CONTROL SYSTEM AND INSTRUMENTATION

There are two different control systems for the Test String 2: an existing ABB control system for the refrigerator and the feed and return boxes, and two Programmable Logic Controllers (PLC) for the magnet string and the jumper modules of the QRL. The two control systems are independent but essential information is exchanged to synchronize and safely operate the overall cryogenic system.

The magnet string process automation [8] is driven by PLCs connected to the field via four Profibus© DP and three Profibus© PA segments. The process management runs in the PLCs, controlling 126 closed control loops, 110 interlocks and 50 alarms. The operator interface is based on industrial software running on PC's and developed in collaboration with an external institute, while the programming of the PLCs has been performed at CERN. About 700 cryogenic sensors and actuators are monitored and controlled via the field buses and the PLC.

The instrumentation includes resistive temperature sensors (Platinum, Cernox™, Carbon), warm and cryogenic pressure sensors, superconducting liquid helium level gauges, warm and cryogenic flowmeters, heaters and warm and cryogenic valves.

The instrumentation and control system, while being increased in number and complexity for diagnostic reasons, is, owing to its relatively large size, representative of a LHC machine sector.

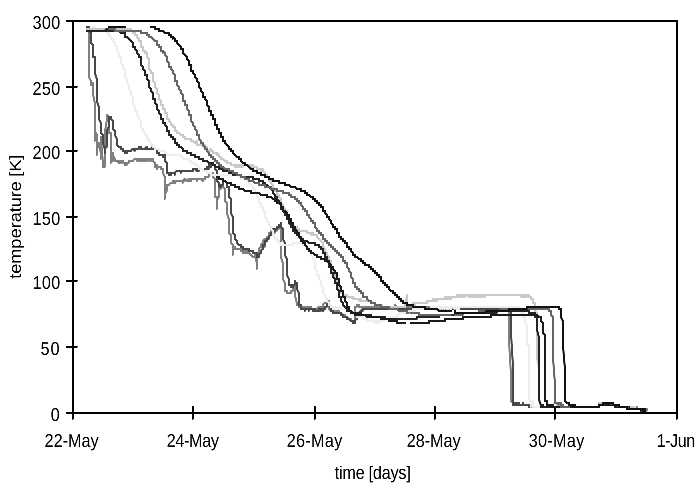

Figure 2 Cooldown from 300 K to 1.9 K: each curve correspond to one magnet

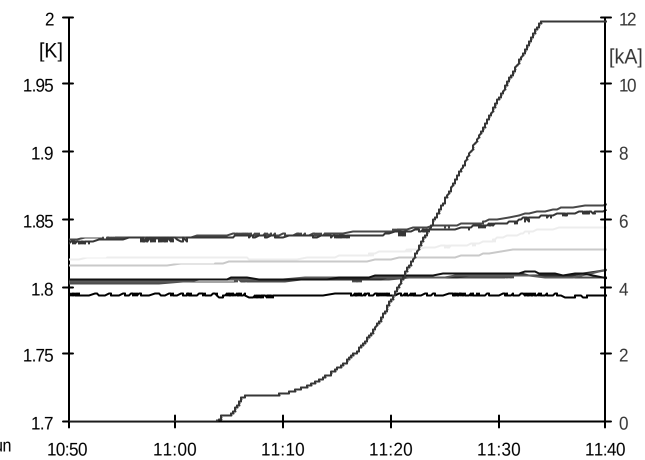

Figure 3 Magnets temperature during powering at nominal current (i.e. 11860 A)

COMMISSIONING

At the end of the Test String 2 assembly, commissioning started with instrumentation and electrical tests, leak testing of all process lines with the magnets interconnects open, evacuation of the vacuum envelope. It was then followed by leak testing of the external vacuum envelope and the process lines in vacuum. After circuits conditioning, leak and pressure testing, the final closure followed by pumping the insulation vacuum. When the pressure was below 10^{-2} mbar the cooldown from 300 K to 4.5 K was performed with a flow of about 80 g/s and a maximum differential temperature between the inlet and outlet of the string of 150 K (Figure 2), which is representative for an accelerated cooldown of the LHC machine. During the cooldown phase all circuits and control loops were progressively commissioned, tuned and then put into operation. At 4.5 K the magnet cold mass was filled with 2200 l of liquid helium and the final part of the cooldown to 1.9 K started by pumping on the bayonet heat exchanger. Once at nominal operating conditions, i.e. 1.9 K on the magnet string and 4.5 K with liquid helium reaching the bottom of the HTS leads in the DFB, additional systems and instrumentation checks took place, followed by fine tuning of all control loops to be ready for magnet powering (Figure 3).

OPERATION AND EXPERIMENTS

The experimental program has been defined to verify the collective behaviour of the LHC systems and components, as well as to optimise future operational performance. The main experiments for the cryogenic system are: final validation of supercritical and superfluid helium loops, evaluation of the process control and the instrumentation under machine-like conditions, investigation of advance control techniques, optimisation of quench recovery procedures, quench propagation and quench relief valves evaluation, long term behaviour of components under electrical and thermal cycling.

During its first phase of operation last year, String 2 has accumulated 1690 hours of operation at 1.9 K, comprising a 24-hours run at nominal current, more than 20 provoked and recovered quenches and an overall availability of nominal cryogenic conditions of 98.8 %.

The superfluid helium loop parameters and characteristics have been validated for the first time in the full test cell final configuration and some limitation of a simple PID controller to control a highly non-linear superfluid helium control loop was observed. The magnet quench tests on a full cell of the machine lattice have shown the propagation of a magnet quench to neighboring magnets of the same half cell and, depending on the quench relief valve opened, to the adjacent cell. Continuous measurements of main component heat loads, in steady-state as well as in transient conditions, have confirmed the order of magnitude of global heat inleaks in the cryogenic system (0.2 W/m at 1.9 K) but have not been conclusive because of the amount of non-standard components and instrumentation peculiar to String 2.

CONCLUSIONS

The Test String 2, as its predecessor String 1, has demonstrated to be a valuable tool to investigate the collective behaviour of systems and components of a complex machine as the LHC prior to installation in the underground tunnel. As a training facility it will permit to identify ways of reducing the assembly and commissioning time, and prepare in advance the LHC operators for the sector test in 2005 and subsequent full machine operation later in 2006.

ACKNOWLEDGMENT

The authors wish to thank E. Fernandez, S. Pelletier, H. Berg and the cryogenic operators.

REFERENCES

1. Casas, J. et al, Operation, Testing and Long Term Behaviour of the LHC Test String Cryogenic System, ICEC-17, IoP, London (1998), 747-750
2. Chorowski, M. et al, A Simplified Cryogenic Distribution Scheme for the Large Hadron Collider, Advances in Cryogenic Engineering (1997), 43A, Plenum, New York, 395-402
3. Barth, K. et al, New Cryogenic Facilities for Testing Superconducting Equipments for the CERN Large Hadron Collider, ICEC-17, IoP, London (1998), 623-626.
4. Erdt, W. K. et al, The Cryogenic Distribution Line for the LHC: Functional Specification and Conceptual Design, Advances in Cryogenic Engineering (2000), 45B, Plenum, New York, 1387-1393
5. Livran, J. et al, A Cryogenic Test Set-Up for the Qualification of Pre-Series Test Cells for the LHC Cryogenic Distribution Line, ICEC-18, Mumbai, India (2000), 227-230
6. Hauviller, C. et al, The Electrical Distribution Feed Box for the LHC Prototype Cell, 7th EPAC, Vienna, Austria (2000)
7. Lebrun, Ph. et al, Cooling strings of superconducting devices below 2 K: the He II bayonet heat exchanger, Advances in Cryogenic Engineering (1997), 43A, Plenum, New York, 419-427
8. Bager, T. et al, Instrumentation, field network and process automation for the cryogenic system of the LHC Test String, 8th ICALEPS (2001), to be published in the proceedings