EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH
European Laboratory for Particle Physics

Large Hadron Collider Project

LHC Project Report 228

New Cryogenic Facilities for Testing Superconducting Equipments for the CERN Large Hadron Collider

K. Barth, J-P. Dauvergne, D. Delikaris, N. Delruelle, G. Ferlin, G. Passardi, J-M. Rieubland

Abstract

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

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Geneva, 24 August 1998

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CERN's major project, the Large Hadron Collider (LHC), has moved to an implementation phase with machine construction to be completed by 2005. To achieve the design proton-proton centre of mass energy of 14 TeV in the given 27 km circumference LEP tunnel, the LHC will make an extensive use of high-field superconducting magnets using Nb-Ti filament operated at 1.9 K. In order to test, on the one hand, the superconducting cables of the magnets and, on the other hand, the expected performance of several of these magnets assembled in a string representing the lattice period of the machine (107 m long), CERN has installed new cryogenic test facilities. The paper briefly describes these new facilities with all their associated equipments.

1. INTRODUCTION

From the cryogenic point of view, the LHC accelerator ring will be composed of about 1'800 high-field superconducting magnets [1] grouped in more than 220 identical and independent cryogenic loops, each of them cooling one magnet string representing a full-cell of the machine lattice. To assess the performance of a LHC prototype full-cell, the existing [1,2] SM18 cryogenic test area had to be upgraded. Furthermore, new test facilities have been set up to test the superconducting wires and the assembled cables which certainly constitute the most critical part of these magnets.

2. TEST FACILITY FOR THE MAGNET STRING

In the framework of its R&D programme, CERN has been operating since February 1995 the first version of a magnet string (String 1), consisting of one 3-m twin aperture quadrupole and three 10-m twin aperture straight dipoles representing altogether a half-cell of the LHC lattice [3]. Although String 1 has yielded a large amount of data and precious operational experience, it was based on an earlier design with dipoles shorter than those foreseen for LHC and with the cryogenic lines traversing the magnet cryostats.

The project management therefore decided to construct a LHC prototype full-cell (String 2), which constitutes the last opportunity, before installation in the tunnel, to validate all the subsystems in their final version both in normal and in exceptional conditions. String 2 will be composed of two half-cells with a total length of $2*53$ m. Each half-cell will consist of a Short Straight Section (SSS) followed by three 15-m dipoles. While the SSS will mainly house a 3-m quadrupole with a field gradient of 223 $T.m^{-1}$ at 12 kA and a sextupole corrector magnet with a strength of 1500 $T.m^{-2}$ at 500 A, the 15-m dipoles will be curved with a nominal bending radius of 2804 m, featuring a 6-block coil cross-section and aluminium collars without magnetic inserts [4].

Thermodynamically, the thermal load of String 2 during its steady-state operation can be expressed in terms of an equivalent total entropy flux of 345 $J.s^{-1}.K^{-1}$ (see table 1). This corresponds to a refrigerator with an equivalent cooling capacity of about 1.6 kW at 4.5 K. Although our existing 6 kW refrigerator manufactured by Sulzer should be sufficient to ensure the steady-state operation, it has been decided to boost this refrigerator by the addition of a liquid nitrogen (LN_2) precooler unit manufactured by Air Liquide in order, on the one hand to cope with the pure liquefaction loads and on the other hand to reduce the cool-down time from 300 K to 90 K of these 160 t of low-carbon steel and aluminium constituting String 2. This LN_2 precooler has been designed to cool 100 g/s of gaseous helium at 80 K.

	Heat loads	Equivalent entropy flux
non-isothermal load between 50 K and 75 K	700 [W]	11.3 [J.s^{-1}.K^{-1}]
non-isothermal load between 4.5 K and 20 K	160 [W]	17.4 [J.s^{-1}.K^{-1}]
50 W isothermal load at 1.9 K, but obtained from the cryoplant as a liquefaction load at 3 bar and 4.5 K	2.5 [g.s^{-1}]	69.3 [J.s^{-1}.K^{-1}]
pure liquefaction load at 3 bar and 4.5 K for HT$_C$ current leads (6∗13 kA + 28∗600 A) and cryostat	2.0 [g.s^{-1}]	55.4 [J.s^{-1}.K^{-1}]
GHe at 20 K for HT$_C$ current leads (6∗13 kA + 28∗600 A) but obtained from the cryoplant as a liquefaction load at 3 bar and 4.5 K	7.0 [g.s^{-1}]	194.0 [J.s^{-1}.K^{-1}]

Table 1: heat loads at steady-state for the 107-m long magnet string representing a full-cell

Similarly to what has been done for String 1, four operating modes are foreseen for the new magnet string test facility. In the first cool-down phase, the temperature will be lowered from 300 K to 90 K by a forced flow of gaseous helium at progressively decreasing temperatures. A fixed gradient of 60 K between the SSS inlet and the last dipole outlet will limit the thermal stresses in the magnets. The second cool-down phase, from 90 K to 4.5 K, will be achieved by filling the magnets with supercritical helium. The third phase, corresponding to the steady-state operation, will start when the magnets are completely filled with liquid helium at 4.5 K; the temperature will then be lowered to 1.9 K by pumping on saturated helium flowing in a longitudinal heat exchanger. The fourth warm-up phase from 4.5 K to 300 K is obtained by circulation of gaseous helium at progressively increasing temperatures, where the 60 K string overall temperature gradient will be again controlled. The cryogenic scheme of this magnet string test facility is shown in fig. 1.

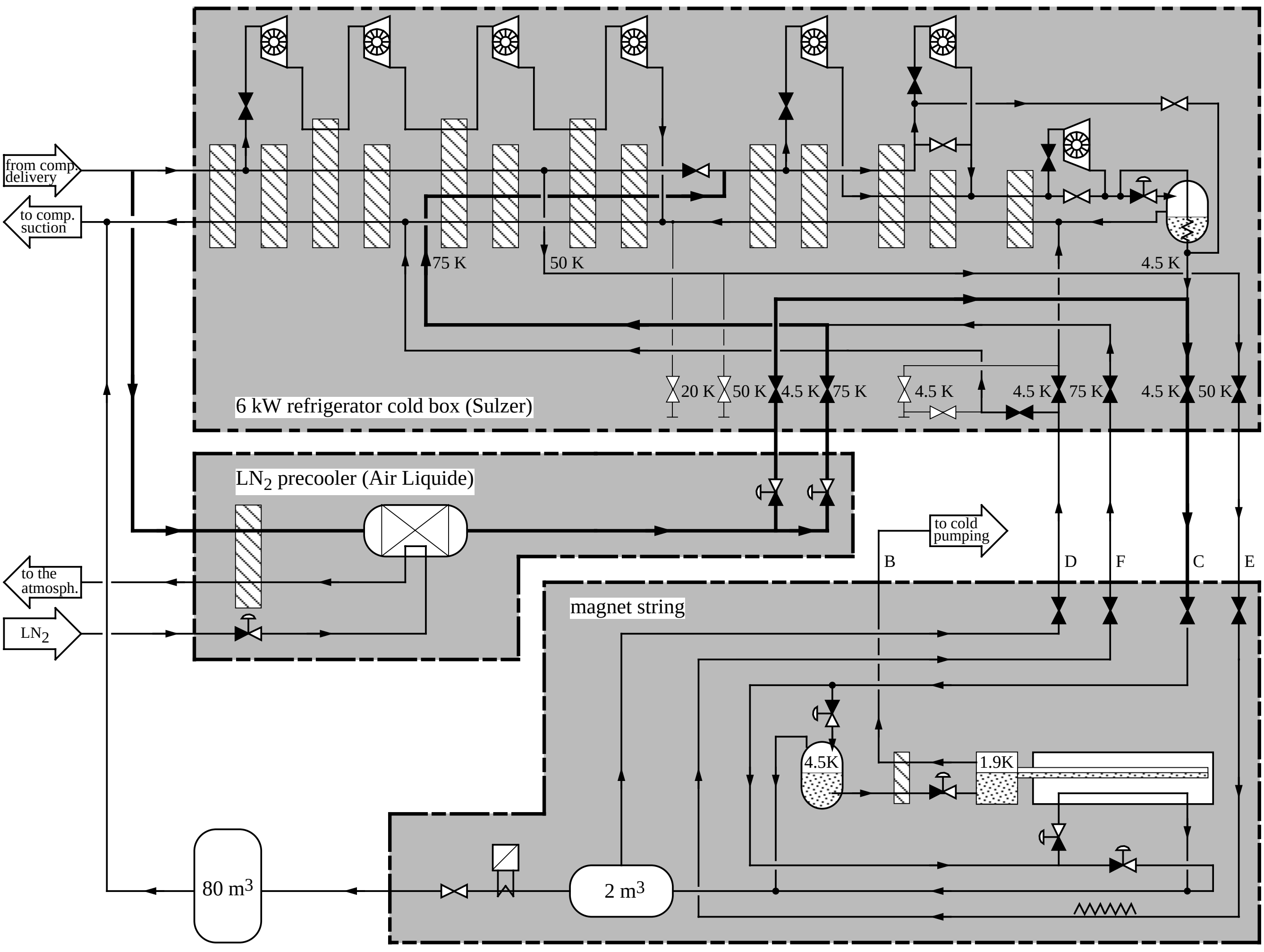

Figure 1: cryogenic scheme of the magnet string test facility at SM18

After having moved from the LEP tunnel to the SM18 test area this 7-year old 6 kW refrigerator and having introduced a brand new control software based on an object-oriented approach, this cryoplant has been re-commissioned during spring 1998 and gave satisfactory results. The next step is the installation and commissioning of the new LN_2 precooler scheduled for September. By the end of 1998, the obtained boosted plant will thus be ready to produce the 38 g/s expected liquefaction rate. But as the new generation of dipoles are not yet available from the industry, String 1 operation will continue until the end of 1998. The assembly of String 2 will extend from mid 1999 to mid 2000, with a first run scheduled in August 2000.

3. TEST FACILITY FOR SHORT DIPOLE MODELS AND CORRECTOR MAGNETS

A cryogenic test station has been set up to evaluate the performance and field quality of the 1-m long models of LHC dipoles and of the corrector magnets. The test facility mainly consists of three vertical cryostats. Inside each cryostat, the magnet is sitting in a pressurised superfluid helium bath at 1.8 K, shielded by a lambda plate. The bath is cooled by a surrounding pipe heat exchanger through which flows superfluid helium at 50 mbar. Each cryostat is equipped with a current feed of max. 20 kA and can be powered in parallel. A fourth cryostat, working in pulsed mode with liquid helium at 4.2 K, is used for quality control of the cold silicon diodes, which will be used in LHC to by-pass the current of a quenched magnet.

All cryostats can be supplied in parallel with liquid helium at 4.2 K via shielded transfer lines from a 2000 l Dewar. This Dewar is at its turn supplied from a dedicated Sulzer TCF200 liquefier boosted with LN_2 to give a maximum liquefaction rate of 150 l/h. The cold box is connected to a GHH MAN screw compressor providing a flow of 80 g/s helium gas at 14 bar with a suction pressure at 1.05 bar. The helium boil-off from the Dewar and the cryostats can be fed back to the liquefier at different temperature levels. The return gas from the pumping station is send back to the warm part of the cold box via a freeze-out purifier which has a capacity of 2 g/s. This purifier consumes about 0.4 g/s of helium and is supplied from the Dewar operated at 1.4 bar. A mechanical pressure control valve operating at 300 mbar gauge protects the Dewar against impurities coming from the pumping station.

The whole cryoplant (compressor, cold box and recovery system) runs fully automatically and is supervised from the LEP1 cryogenic control room. The test facility is run continuously all through the year with only a 4-week maintenance shutdown. During 1997, in addition to the dipole models and silicon diodes that were tested, the performances of the LHC corrector magnets have been measured at cryogenic temperatures [5].

4. TEST FACILITY FOR SUPERCONDUCTING WIRES AND CABLES

A new cryogenic test area is built to test superconducting wires and the assembled cables. The test facility will include seven small cryostats for wire measurements and one large assembly (FRESCA) dedicated for measuring the critical current of the assembled cables [6]. Five of the seven small cryostats will work with superfluid helium at 1.8 K, while the other two will use liquid helium at 4.2 K. The superfluid helium will be obtained by pumping a helium bath from atmospheric pressure down to 50 mbar. A pumping station is therefore installed which provides a heat load of 3 W at 1.8 K per cryostat. The FRESCA assembly actually consists of two cryostats. The external cryostat contains the superconducting magnet which can provide a magnetic field of up to 10 T at a maximum current of 14 kA. The inner cryostat houses two 1-meter long cable samples, which can be supplied with a maximum current of up to 32 kA. The sampler holder can be turned by 90 degrees to study the critical current for a field perpendicular to the small and large cable faces. The pumping station dedicated to FRESCA has a total heat load of 20 W at 1.8 K.

All users of cryogens are supplied from a dedicated TCF50 helium liquefier boosted with LN_2, providing a maximum liquefaction rate of 160 l/h. The cold box is connected to a Kaeser screw compressor supplying 80 g/s high pressure helium gas at 13 bar. The seven small cryostats are supplied directly from the cold box with liquid helium via a nitrogen shielded transfer line which is connected at its end to a 6000 l Dewar. The FRESCA assembly is supplied from this Dewar. The liquid helium consumption of a small cryostats is expected to be around 2 g/s, while the maximum consumption of the FRESCA during operation will be in the range of 7-10 g/s.

During operation of this test facility, an additional gaseous return flow of up to 400 m^3/h will be sent to the helium recovery system. Therefore the existing infrastructure has been extended by a new Sulzer Burckhardt recovery compressor with a maximum capacity of 420 m^3/h which feeds two 200 m^3/h Linde helium purifiers formerly used at the LEP collider. The existing low and high pressure helium storage capacity has been upgraded to cope with the increasing total gaseous helium inventory. A new control system is currently installed to operate the whole infrastructure fully automatically.

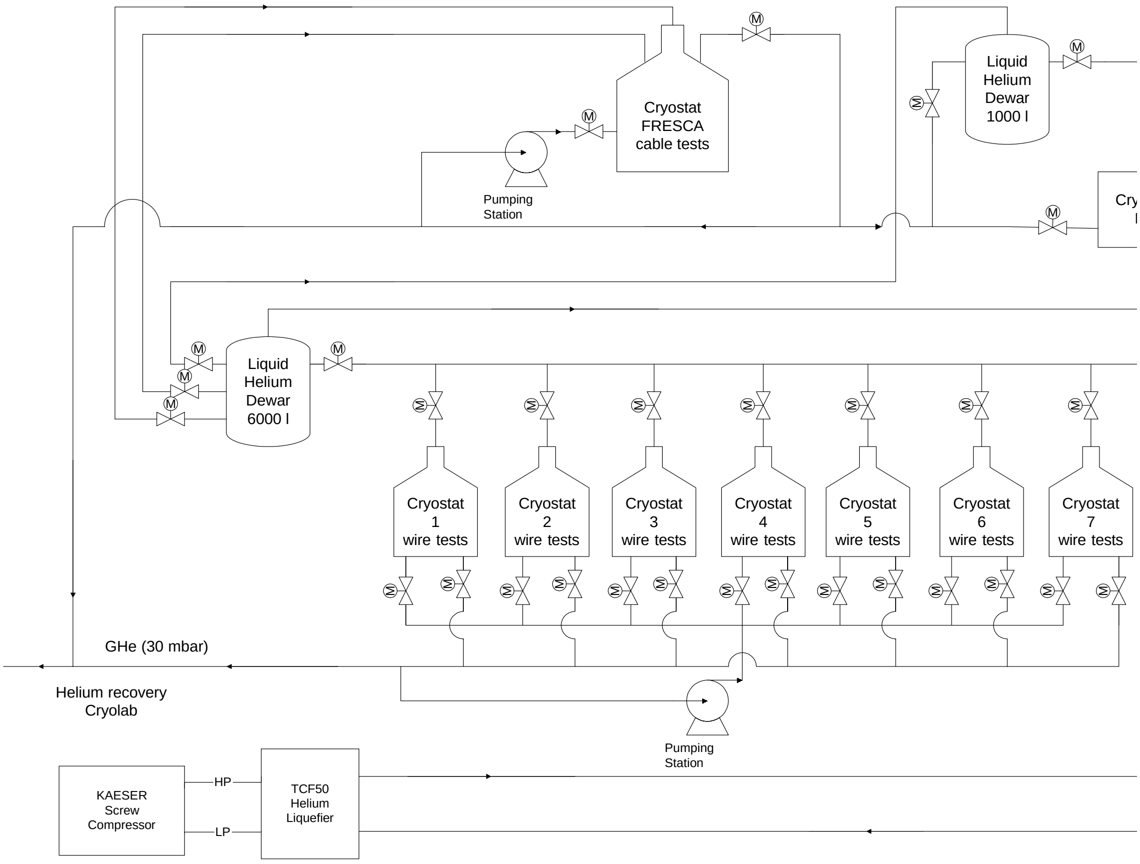

Figure 2: flow scheme of the superconducting wires test facility

5. CONCLUSION

Testing of superconducting magnets and Nb-Ti cables at 1.9 K for the LHC has drastically increased and diversified the different cryogenic test facilities at CERN. The major part of these facilities has been already installed while commissioning work is still under progress.

6. REFERENCES

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