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Cryogenic Infrastructure for Testing of LHC Series Superconducting Magnets

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Abstract

The ~1800 superconducting magnets for the LHC machine shall be entirely tested at reception before their installation in the tunnel. For this purpose and in order to reach the reliability and efficiency at the nominal load required for an industrial operation for several years, we have gradually upgraded and retrofitted the cryogenic facilities installed in the early nineties for the testing at CERN of prototypes and preseries magnets. The final infrastructure of the test station, dedicated to check industrially the quality of the series magnets, is now nearly complete. We present the general layout and describe the overall performance of the system.

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INTRODUCTION

In the 1990's, in order to fulfil the development and preparatory work program for the design of the LHC arc superconducting magnets, hereafter called cryomagnets, CERN has constructed a dedicated cryomagnet test facility [1] in an existing 7200 m^2 floor space hall, so-called SM18. The first cryogenic test bench [2] started to operate in spring 1994, for the test of the first 10-metre long, 18-ton prototype superconducting twin-aperture dipole operating at 1.8 K. In the years that followed, many few prototype-cryomagnets from different versions and suppliers were tested on this prototype test bench.

Early 1997, in order to deal with the updated cryomagnets characteristics and test program (*e.g*. 15-m long, 27.5-t series arc dipoles with new position of hydraulic interfaces), we launched the upgrade of the cryogenic infrastructure in terms of installed test capacity & reliability (redundancy of sub-systems), and the procurement of the modular interfaces between the infrastructure and the cryomagnets to be tested. The final number of test benches was set to twelve, as a maximum number for the available space in the test area forming a reasonably adequate plant for the entire reception-testing in turn and in a 3-year time of the 1722 series high-field, twin-aperture, superconducting arc cryomagnets for the LHC machine.

SYSTEM LAYOUT

The basic objective was to deliver or circulate the required existing or upgraded cryogenic utilities to a modular distribution system of which individual elements (the test benches) offered the widest possible range of independent relative operating conditions, *i.e.* giving the highest possible flexibility for operation. From the experience gained with the intensive operation of the test station with the prototype and the first two preseries test benches [3], we clearly finalized how each type of utility could be shared among the benches, according to criteria such as reliability, built-in redundancy, possible operation errors, controllability, flexibility, efficiency, available space and last but not least, budgetary conditions.

<u>Cryogenic Utilities</u>

The following central utilities or systems are shared, each of them being given, according to the selected criteria, not any, limited or full redundancy: the liquid nitrogen storage, the liquid nitrogen distribution, the cryomagnets Cooldown Warmup System (CWS), the refrigeration plant, the helium storage, the Cryogenic Compound Line (CCL) for helium distribution & return and the 1.9 K pumping facility.

The liquid nitrogen storage consists of two 50'000 litre vessels connected in parallel. The first one is filled up to a daily basis according to the actual consumption of the test station while the second one is maintained full enough in order to ensure an additional 2-day autonomy in case of a delayed liquid nitrogen delivery. A 120-metre long liquid nitrogen transfer network feeds the CWS with up to 500 g/s of liquid nitrogen withdrawn from the selected storage vessel.

The CWS can be schematized as a box including two twin manifold terminals able to circulate to the selected test benches gaseous helium at 80 K for cooldown and at 320 K for warmup of cryomagnets. It consists of 2 twin 100 g/s @ 0.2 MPa helium screw compressors-oil removal units delivering an outlet pressure of 1.2 MPa, connected in parallel to twin cooldown units (CWU1 and CWU2) designed in order to extract a cooling power of up to 120 kW @ 80 K, thanks to the helium circulated through their counter-flow heat exchanger-liquid nitrogen vaporiser. On the other hand, the built-in 25 kW warmup function of both CWU, definitely insufficient for the series test duty, is disabled in order to dedicate both CWU to the cooldown function only, thus doubling the average total cooldown power of these two formerly procured units. The CWS warmup function is now performed by dedicated units consisting of enhanced industrial immersion electrical heaters fitted in vacuum-isolated envelopes. A first 30 kW heater heats up from ambient temperature up to 320 K the gaseous helium delivered by the compressors to be circulated to the cryomagnets while the second 200 kW one heats up from its actual temperature in the range [5 K – 295 K] up to 295 K the circulated helium returned from the cryomagnets. Eventually, a 30 m^3 gaseous helium buffer allows the charge or the discharge of the amount of helium gas in the circulation loop (variable number of connected cryomagnets, at variable pressure and temperature). Most of the above-mentioned subassemblies are integrated by means of a 60-metre long, 4-header, compound vacuum isolated network housed in a 400-mm diameter vacuum envelope and equipped with twelve valve boxes. Each one of the CWS valve boxes is connected *via* a vacuum barrier to one Cryogenic Feed Box (CFB), which represents the complex (cryogenic-mechanic-electrical) interface between the infrastructure and the cryomagnet under test. Thanks to the isolating vacuum, the acoustic vibrations emitted by the inner header passing the warmup flow rate of up to 180 g/s @ 320 K are significantly damped. The very last upgrading of the CWS is scheduled for end-2004, when the two oil removal systems forming the present limitation to the installed circulation capacity will be replaced, in order to handle individual helium flow rates of up to 150 g/s @ 1.0 MPa. This will result in a CWS maximum capacity of 300 g/s @ 0.3 MPa with the two existing compressors only, *i.e.* more than three cryomagnet cooldown and three cryomagnet warmup can be carried out daily. For additional flexibility of operation and redundancy reasons, a third 150 g/s @ 0.3 MPa helium screw compressor-oil removal unit will be installed by the same time.

The CCL consists mainly of three headers housed in a 400-mm diameter vacuum envelope and twelve valve boxes, each of them being connected to one CFB *via* a vacuum barrier. Two of these headers replace the original network of flexible helium transfer lines as well as the former helium phase separator-liquid distribution box (LDB). The main drawback of the former helium distribution system was that it imposed a LDB operating pressure at 0.135 MPa for the withdrawing of the required flow rate of helium from the liquid helium storage. This intermediate pressure stage was creating a loss of efficiency, as the flash gas due to the 150 kPa isenthalpic expansion had to return directly to the refrigerator. Moreover, it would have been impossible to increase the operating pressure of this liquid helium distribution system at a value high enough compatible with the 0.13 MPa cold return pressure imposed by the process of the new 18 kW @ 4.5 K refrigerator cold box [4]. Therefore, the first 30-mm diameter header of the CCL distributes to the twelve CFB up to 60 g/s of saturated liquid helium at 0.14 MPa withdrawn from the 25'000-litre dewar. The dewar operates at 0.16 MPa and is fed through a ~200-metre long, 2-header cryogenic line, by the refrigerator operating mostly in liquefier mode. The second 86-mm diameter header of the CCL collects the gaseous helium returned from the twelve CFB in the [5 K – 90 K] temperature range while ensuring the active cooling of the CCL thermal shield. As a rule, for flow rates of up to 60 g/s at temperatures of up to 50 K, this gaseous helium is sent to the cold return line of the refrigerator, at 0.13 MPa. For higher flow rates or temperatures, the gaseous helium flow rate is partly redirected to the warm return line to the refrigerator, at 0.1 MPa, *via* an electrical heater of a power up to 100 kW. The third 150-mm diameter header of the CCL collects the cold gaseous helium from the pumping ports of the CFB1.9 K subcooling heat exchangers. Its outlet is connected to the 1.9 K pumping facility.

The 1.9 K pumping facility consists of two parallel branches. The first one, of a pumping capacity of 18 g/s @ 1.2 kPa, 5 K, includes a precompression stage performed by a cold centrifugal compressor unit [5], a combined valve box-32 kW electrical heater [6] and the low-pressure gaseous helium pumping unit installed in 1993 in the neighbouring building. The second branch with a present pumping capacity of 7.2 g/s @ 1.2 kPa includes since 2003 the twin of the former 32 kW electrical heater in series with the twin of the former low pressure pumping unit. This branch is ready to receive a combined valve box-precompression stage unit [7] presently under integration, in order to ensure the full redundancy of the 18 g/s @ 1.2 kPa, 5 K pumping capacity from end-2004 on. Special attention was paid for the design of circuits (use of helium guards, monitoring of oxygen residual content …). The present pumped helium flow rate of up to 25.2 g/s is presently redirected to the warm return line to the refrigerator.

Cryogenic Feed Boxes

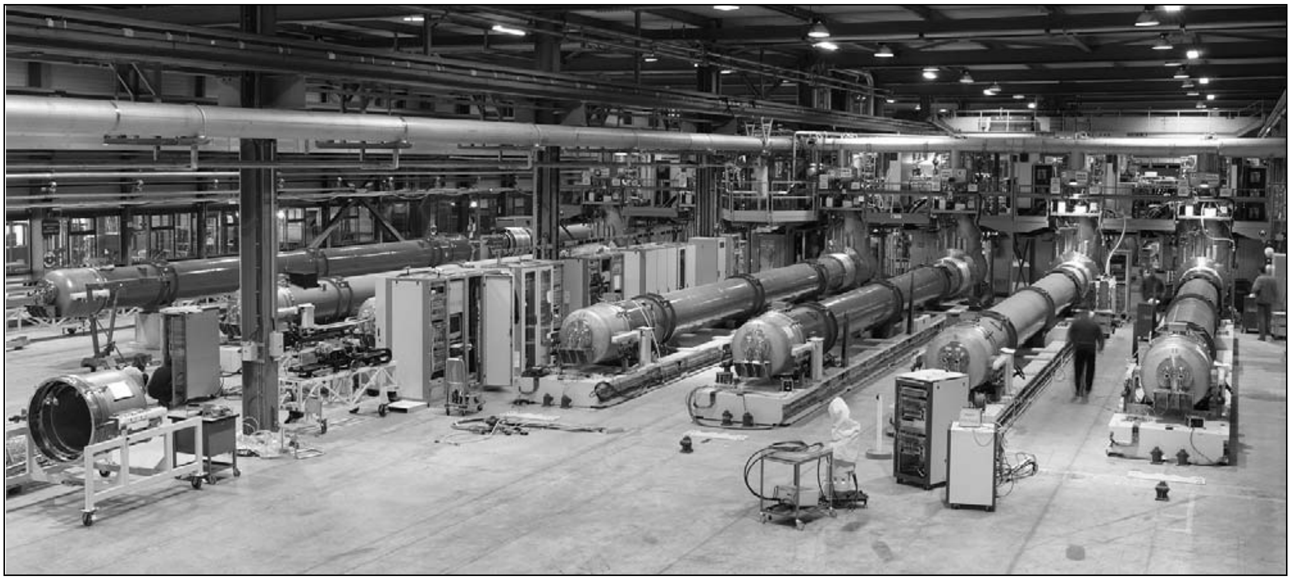
From the experience gained with the construction at CERN and operation of the first feeder unit so-called Magnet Feed Box (MFB), and with the turn-key procurement from industry of the two preseries feeder units, so-called the Cryogenic Feeder Units (CFU), we decided to reorganize the production for the procurement of twelve series units, the CFB. We decided to procure the critical components of the CFB separately and to specify their final integration by the contractor of CFB, the control system remaining under CERN responsibility.

As seen above, the CFB is the complex interface between the infrastructure and the cryomagnet under test. Each CFB is precisely positioned and bolted on a metallic inertia structure and fits a formerly allocated space delimited by a platform and other ancillary equipment. A CFB comprises mainly helium pipework and helium-cooled, high-current circuits installed within a thermally insulated vessel. Its subassemblies are the following: a vacuum vessel, an actively-cooled thermal shield covered with multilayer insulation, a helium vessel, a gas-liquid subcooling heat exchanger [8], a set of main current lines, a pair of 15 kA current leads [9], four auxiliary superconducting current lines, four 600 A current leads [10], inner supports, internal and external pipework, a rough pumping set, a turbomolecular pumping set, a helium leak detection set, a purge panel and industrial instrumentation for remote control and monitoring. The innovative features of the CFB are the following:

- a single inner vessel ensures the functions of phase separation, level and flow rate measurement of liquid helium (two measurements based on head of liquid/orifice principle), buffering of liquid helium for feeding the current-lead baths by head of liquid and finally retro-transfer of liquid helium and storage at up to 1.8 MPa of supercritical helium after resistive transition (quench) of the cryomagnet;
- the whole set of 15 kA power circuits can be easily located in two positions over 290 mm in a nearly vertical plane in order to be connected to the main busbars of the two different families of cryomagnets, *i.e.* arc dipoles, short straight sections;
- a dry pump is used for the heavy-duty repetitive rough pumping (~10'000 ppm weigh of humidity in the initially evacuated air) in a self-limiting way (the multilayer insulation tolerates maximum –10 kPa/s) down to 1 Pa of the ~10-m^3 volume of the CFB-cryomagnet assembly vacuum vessel. The dry pump tolerates 5 years of operation without any maintenance;
- the six hydraulic interfaces to the cryomagnet (the only non-welded inner pipes of the CFB-cryomagnet assembly) make use of compact, single-use double metallic sealing. This sealing technique for such circuits operating in vacuum with superfluid helium at 1.9 K allows fast automatic helium leak detection of the flanged connections and even allows the operating at cryogenic conditions with significant –but unusual– leaks, without impairing the mandatory global helium leak measurement of the cryomagnet under test, by means of temporary or continuous pumping of the interspaces;
- the two hydraulic interfaces housing the *in situ*-soldered provisional electrical junctions of the cryomagnet busbars to the CFB main and ancillary superconducting lines, respectively, consist of two especially designed retractable sleeves (diaphragm bellows working under an external pressure of up to 2.5 MPa) for the quickest possible hydraulic connection;
- all the instrumentation of the CFB high voltage or high current electrical circuits, those in warm gaseous helium at 0.13 MPa included, are designed in order to withstand in normal operation and with significant contingency the repetitive electrical insulation tests at up to 3.1 kV of the cryomagnets coils .

CONCLUSION

This test infrastructure is presently operated 24 hours a day, 7 days per week. The achieved peak capacity is two LHC 15-m long, 27.5-t arc dipoles tested daily. Thanks to the control system and to the recently developed dedicated tools for coordinating the work of the involved teams of operators [11], thus taking the maximum advantage of the installed or upgraded systems resulting from this layout, we do believe that the final average capacity will fulfil the requirements for the cryogenic test of all LHC cryomagnets.



Photograph 1 SM18, partial view of infrastructure for testing of LHC superconducting magnets

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REFERENCES

1. Benda, V., Duraffour, G., Guiard-Marigny, A., Lebrun, P., Momal, F., Saban, R.I., Sergo, V., Tavian, L., Vullierme, B., Cryogenic Infrastructure for Superfluid Helium Testing of LHC Prototype Superconducting Magnets, International Cryogenic Engineering and Materials Conference Albuquerque, NM, USA (1993)
2. Benda, V., Granier, M., Lebrun, P., Novellini, G., Sergo, V., Tavian, L., Vullierme, B., Cryogenic Benches for Superfluid Helium Testing of Full-Scale Prototype Superconducting Magnets for the CERN LHC Project, International Cryogenic Engineering Conference Genova, Italy (1994)
3. Benda, V., Vullierme, B., Schouten, J.A., Experience with a Pre-Series Superfluid Helium Test Bench for LHC Magnets, International Cryogenic Engineering Conference – 18 Mumbai, India (2000)
4. Calzas, C., Chanat, D., Knoops, S., Sanmartí, M., Serio, L., Large Cryogenic Infrastructure for LHC Superconducting Magnet and Cryogenic Component Tests : Layout, Commissioning and Operational Experience, Cryogenic Engineering Conference and International Cryogenic Materials Conference Anchorage, AK, USA (2003)
5. Decker, L., Löhlein, K., Schustr, P., Vins, M., Brunovsky, I., Lebrun, P., Tavian, L., A Cryogenic Axial-Centrifugal Compressor for Superfluid Helium Refrigeration, International Cryogenic Engineering Conference / International Cryogenic Materials Conference – 16 Kitakyushu, Japan (1996)
6. Benda, V., Sergo, V., Vullierme, B., Electrical Heater For Very-Low Pressure Helium Gas, Kryogenika Prague, Czech Republik (1996)
7. Saji, N., Asakura, H., Yoshinaga, S., Itoh, K., Nogaku, T., Bézaguet, A., Casas-Cubillos, J., Lebrun, P., Tavian, L., A One kPa Centrifugal Cold Compressor for the 1.8 K Helium Refrigeration System of LHC, International Cryogenic Engineering Conference – 17 Bournemouth, UK (1998)
8. Roussel, P., Bezaguet, A., Bieri, H., Devidal, R., Jager, B., Moracchioli, R., Seyfert, P., Tavian, L., Performance Tests of Industrial Prototype Subcooling Heat Exchangers for the Large Hadron Collider, Advance in Cryogenic Engineering (2001) Volume 47b 1429-1436
9. Andersen, T P., Benda, V., Vullierme, B., Series Production of 13 kA Current Leads with Dry and Compact Warm Terminals, Paper presented at this conference
10. Andersen, T P., Benda, V., Vullierme, B., 600 A Current Leads with Dry and Compact Warm Terminals, 7th Cryogenics IIR International Conference Prague, Czech Republic (2002)
11. Axensalva, J., Herblin L., Lamboy JP., Tovar-Gonzalez, A. and Vullierme, B., Control System and Operation of the Cryogenic Test Facilities for LHC Series Superconducting Magnets, Paper presented at this conference