

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH
European Laboratory for Particle Physics



Large Hadron Collider Project

LHC Project Report 616

**A CRYOGENIC TEST STATION
FOR THE PRE-SERIES 2400 W @ 1.8 K REFRIGERATION UNITS
FOR THE LHC**

S. Claudet¹, G. Ferlin¹, Ph. Gully², B. Jager², F. Millet², P. Roussel² and L. Tavian¹

Abstract

The cooling capacity below 2 K for the superconducting magnets in the Large Hadron Collider (LHC), at CERN, will be provided by eight refrigeration units at 1.8 K, each of them coupled to a 4.5 K refrigerator. The supply of the series units is linked to successful testing and acceptance of the pre-series delivered by the two selected vendors. To properly assess the performance of specific components such as cold compressors and some process specificities a dedicated test station is necessary.

The test station is able to process up to 130 g/s between 4.5 & 20 K and aims at simulating the steady and transient operational modes foreseen for the LHC. After recalling the basic characteristics of the 1.8 K refrigeration units and the content of the acceptance tests of the pre-series, the principle of the test cryostat is detailed. The components of the test station and corresponding layout are described. The first testing experience is presented as well as preliminary results of the pre-series units.

1 LHC Division, CERN, Geneva, Switzerland
2 SBT, DRFMC, DSM, CEA, Grenoble, France

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

A cryogenic test station for the pre-series 2400 W @ 1.8 K refrigeration units for the LHC

Claudet S., Ferlin G., Gully Ph.*, Jager B.*, Millet F.*, Roussel P.*, Tavian L.

LHC Division, CERN, 1211 Geneve 23, Switzerland

*SBT, DRFMC, DSM, CEA, 17 avenue des martyrs, 38054 Grenoble, France

The cooling capacity below 2 K for the superconducting magnets in the Large Hadron Collider (LHC), at CERN, will be provided by eight refrigeration units at 1.8 K, each of them coupled to a 4.5 K refrigerator. The supply of the series units is linked to successful testing and acceptance of the pre-series delivered by the two selected vendors. To properly assess the performance of specific components such as cold compressors and some process specificities a dedicated test station is necessary.

The test station is able to process up to 130 g/s between 4.5 & 20 K and aims at simulating the steady and transient operational modes foreseen for the LHC. After recalling the basic characteristics of the 1.8 K refrigeration units and the content of the acceptance tests of the pre-series, the principle of the test cryostat is detailed. The components of the test station and corresponding layout are described. The first testing experience is presented as well as preliminary results of the pre-series units.

INTRODUCTION

The cooling capacity below 2 K for the superconducting magnets in the Large Hadron Collider, at CERN, will be provided by eight refrigeration units at 1.8 K, each of them coupled to a 4.5 K refrigerator [1]. The 1.8 K refrigeration units have been specified in 1998 and ordered in 1999 [2,3,4].

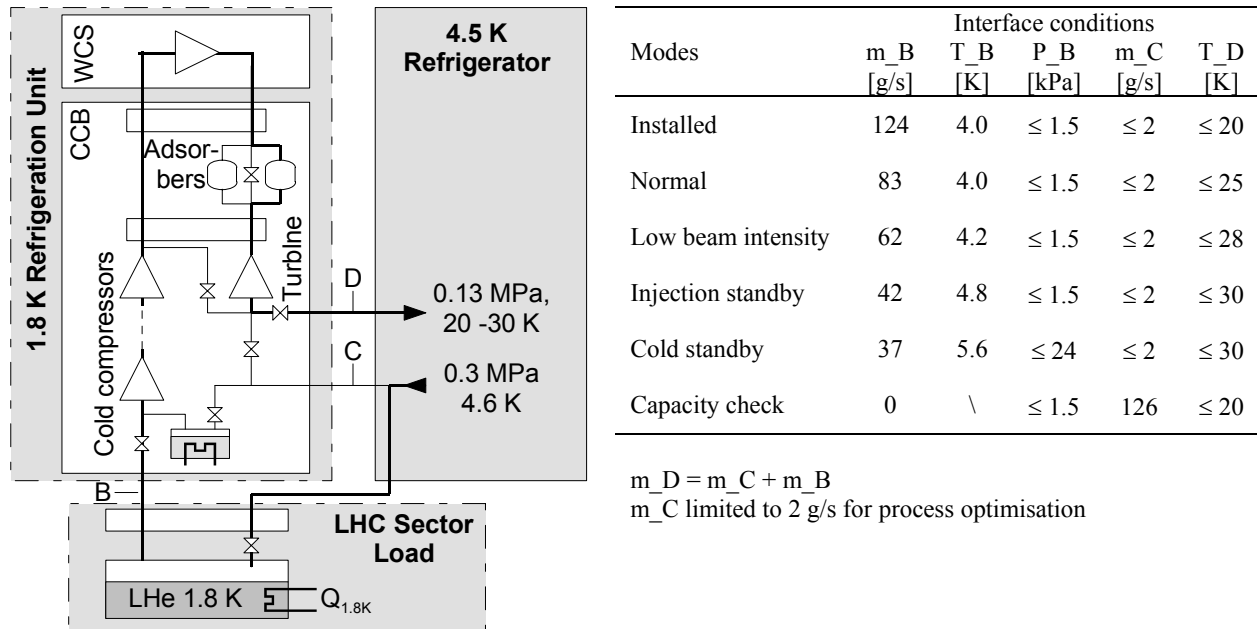


Figure 1 Generic scheme of a 1.8 K refrigeration unit and interface conditions for different steady-state modes

Figure 1 shows a typical flow scheme of a 1.8 K refrigeration unit as well as the interface conditions with the LHC (header B) and a 4.5K refrigerator (headers C and D) for the different steady state operation modes. Transients considered are cool-down, pump-down to 1.5 kPa, pumping flow variation up to ± 6 g/s per minute. In order to validate the process and components, a first “pre-series unit” has to be validated by extensive testing at CERN before launching production of series unit.

The testing method and means had to be defined. With the possibility to supply supercritical helium to the 1.8 K units, it could be envisaged to establish the required pressure, temperature and flow conditions within the built-in phase separator of the Cold Compressor Box (CCB). However, the ability to perform some transients with cold compressors (CC) could have required additional flow at lower temperature, which could only be produced within the built-in phase separator of CCB. It was therefore decided to generate the required conditions by means of a dedicated cryostat.

TEST STATION DESCRIPTION

The required equivalent cooling capacity for the test station is about 7 kW at 4.5 K. To minimise the cost impact, it was decided to make use of the first new 18 kW at 4.5 K refrigerator for LHC, see Figure 2, also used to supply the magnet test station. For housing the test equipment, some place was made available in a nearby building. A compact design for the test facilities area and test cryostat was therefore required. The installation and integration of the main components and associated structures have required delicate integration studies which have constituted a good exercise for layout studies in LHC underground caverns.

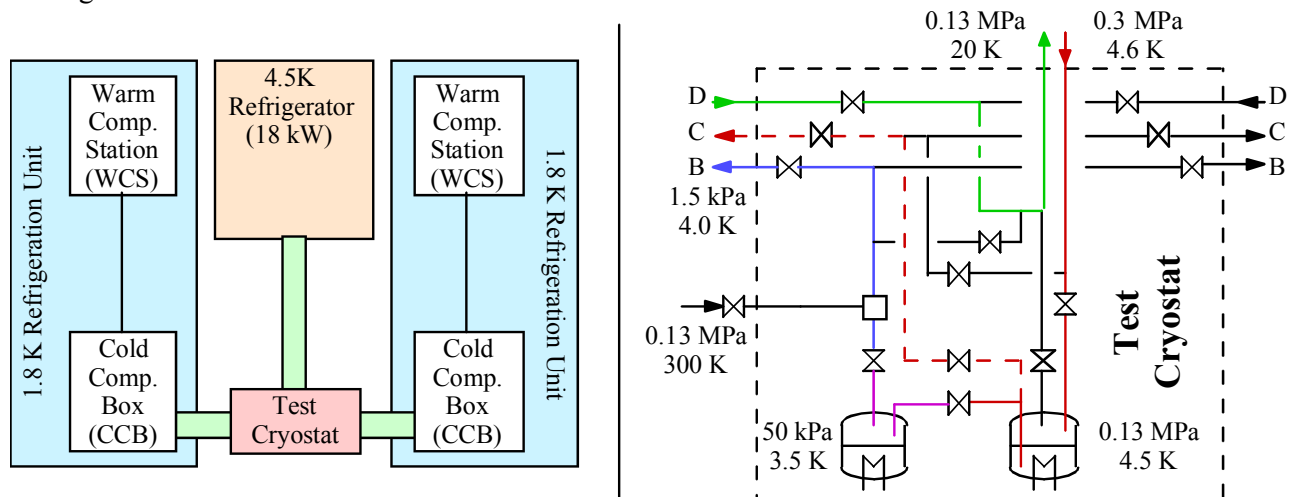


Figure 2 Simplified schemes of pre-series 1.8 K refrigeration unit test station and test cryostat

Utilities and piping

Utilities such as electrical power, cooling water, instrument air, interconnecting piping has been defined early enough to be handled with final LHC infrastructure in the zone which minimised the corresponding cost and manpower. The only specific tasks was the L 14 m x W 6 m x H 4 m excavation to provide the necessary 9.6 m clearance below crane hook for the two CCB and self supporting structures.

Test cryostat

Various process design alternatives have been studied to guarantee better than ± 1 % accuracy for the header B mass flow rate, ± 0.1 K for headers B and C temperatures and ± 3 kPa for headers C and D pressures. The common principle was to combine the vapour fraction produced after J-T expansion with electrical heater boil-off to generate the required gas flow. Using a single phase separator would have provided some ± 2 % accuracy only whereas ± 0.2 % could be achieved with two phase separators in series. This is mostly due to well defined and controlled pressure conditions in both phase separators. The working pressure of the second bath has been chosen at 50 kPa corresponding to saturated temperature equal to 3.5 K to ease simulation of LHC temperatures and pressures. Once the flow scheme had been

finalised and procurement of 1.8 K refrigeration units split between both compliant tenderers in spring 1999, conceptual drawings were made by CEA. A manufacture contract based on “built to print” basis was placed between CERN and SNLS (F) in June 2000 for a delivery in June 2001. First cool down was made in autumn 2001 and automatic operation and fine tuning of the cryostat took place early March 2002.

Transfer lines

The 7 m long compound transfer lines to connect each CCB to the test cryostat were supplied together with the cryostat. Installation and welding was done after delivery of corresponding CCB.

The 100 m long lines to and from the 4.5 K refrigerator were purchased separately. Due to the double phase separator scheme and chosen pressure levels of the test cryostat, the heat input and pressure drop constraints were not so stringent. After competitive tendering during summer 2000, a contract was placed between CERN and Air Liquide (F) in October for two similar independent lines with inner tubes (100 mm) made of Invar M93® supplied by USINOR (F). After specific metallurgical, design validation and manufacture follow-up, delivery started July 2001 and first cool-down took place in October.

Controls and data archiving

For similar low-cost impact reasons, hardware and software are the first implementation of what is intended for the LHC cryogenic control system, considering the test cryostat as a small “interconnecting box”. The first year has been sometime tedious until the system could be fully operational. Long term data archiving and retrieval is made using the nearby LHC magnet test string set-up which is already existing and maintained.

OPERATING PRINCIPLES

The operation team in charge of the 4.5 K refrigerator delivers a signal “1.8 K unit testing authorised”. When the later is validated, it is possible to connect automatically the test cryostat. When desired, manual isolation valves towards a CCB are opened. This validates the possibility to connect a CCB if already pre-cooled at 20 K by their own turbines. After cool-down of the lines, pump down could be started. Sets of predefined values of mass flow rate and temperature to be generated corresponding to specified steady state modes could be selected, with variable changing ramp speeds used to test transients. Alternatively, the operator in charge of the test station could select any specific value up to the maximum ones. Switch between 1.8 K units could be made within 2 hours thanks to set of manual valves for transfer lines towards each pre-series.

At maximum, it is envisaged to have both CCB connected to the test cryostat with adapted operation modes compatible with the total available capacity. Depending on the test program, the cryostat could be set in cold stand-by for which the supply from the 4.5 K refrigerator is stopped. Automatic warm-up of the cryostat and lines is usually performed if there are no tests foreseen within a week.

FIRST RESULTS

Cool-down to 4.5 K is made automatically within 5 hours to accommodate operating constraints at the 4.5 K refrigerator. The connection with pre-series is relatively tricky, as helium inventory in 1.8 K units at 20 K is only about 200 m³ NTP to be compared with 850 m³ NTP when cooled and ready for pump-down. This transfer of mass implies adaptations of operating settings at the warm compressor station (WCS) and this sequence is not yet fully automatic.

Flow towards cold compressors could be achieved with stability of ± 0.5 g/s (for values from 40 to 130 g/s) and ± 0.1 K (for values between 4 to 5 K) over several hours with good de-coupling with respect to fluctuations at the 4.5 K refrigerator. For transients, turn down capability of three has been demonstrated with specified changes in flow rate of ± 6 g/s per minute with maximum 200 Pa increase at suction pressure and at maximum up to ± 10 g/s per minute with 500 Pa increase (see Figure 3). All

steady states and transients have been performed several times with unnoticeable effects on the 1.8 K refrigeration unit.

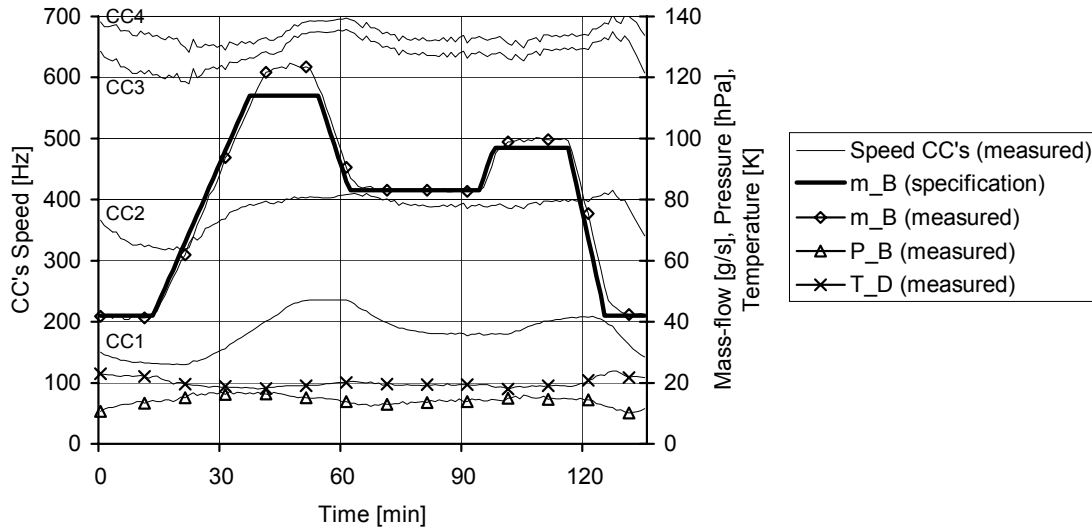


Figure 3 Typical specified transients and corresponding measured values

CONCLUSION

With a testing strategy defined early in the project, it has been possible to build up a test station for pre-series 1.8 K refrigeration units at a cost limited to 4 % of the total cost of the eight 1.8 K refrigeration units. The test cryostat concept proved to be adapted. Weekly operation is performed by a single trained operator using pre-programmed sequences. It has been in operation since the beginning of 2002 and allows extensive testing of pre-series 1.8 K refrigeration units. One pre-series has already been accepted in June 2002 [5] and the second is being tested [6]. In the future, the test station will be used to validate cold compressor cartridges for series as foreseen and will as well be used to test alternative principles for specific transients. Series deliveries at CERN are expected from autumn 2003 to spring 2005. At present, this is six to eighteen months ahead of operation for respective LHC sector cool-down.

ACKNOWLEDGEMENTS

The authors would like to thank all colleagues involved in defining, building-up and operating this test station.

REFERENCES

1. Millet, F., Roussel, P., Taviani, L. & Wagner, U., A Possible 1.8 K Refrigeration Cycle for the Large Hadron Collider, paper presented at CEC'97 Portland, USA.
2. Claudet, S., Gayet, P., Jager, B., Millet, F., Roussel, P., Taviani, L. & Wagner, U., Specification of eight 2400W @ 1.8K refrigeration units for the LHC, paper presented at ICEC18 Mumbai 2000, India
3. Asakura, H., Honda, T., Mori, M., Yoshinaga, S., Bosel, J., Kündig, A., Kurtcuoglu, K., Meier, A. and Senn, A.E., Four 2400 W / 1.8 K refrigeration units for CERN-LHC: the IHI/Linde system, paper presented at ICEC18 Mumbai 2000, India
4. Hilbert, B., Gistau-Baguer, G. and Dagut, F., 2.4 kW at 1.8 K refrigeration units for CERN LHC project supplied by Air Liquide, paper presented at ICEC18 Mumbai 2000, India
5. Asakura, H., Kündig, A., Control considerations of multi stage cold compression systems in large refrigeration plants, paper presented at this conference
6. Hilbert, B., Monneret, E., Walter, E., Experimental results obtained with the AL 1.8 K refrigeration pre-series unit for CERN LHC project, paper presented at this conference