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LARGE CRYOGENIC INFRASTRUCTURE FOR LHC SUPERCONDUCTING MAGNET AND CRYOGENIC COMPONENT TESTS: LAYOUT, COMMISSIONING AND OPERATIONAL EXPERIENCE

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Abstract

The largest cryogenic test facility at CERN, located at Zone 18, is used to validate and to test all main components working at cryogenic temperature in the LHC (Large Hadron Collider) before final installation in the machine tunnel. In total about 1300 main dipoles, 400 main quadrupoles, 5 RF-modules, eight 1.8 K refrigeration units will be tested in the coming years.

The test facility has been improved and upgraded over the last few years and the first 18 kW refrigerator for the LHC machine has been added to boost the cryogenic capacity for the area via a 25,000 liter liquid helium dewar. The existing 6 kW refrigerator, used for the LHC Test String experiments, will also be employed to commission LHC cryogenic components.

We report on the design and layout of the test facility as well as the commissioning and the first 10,000 hours operational experience of the test facility and the 18 kW LHC refrigerator.

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ABSTRACT

The largest cryogenic test facility at CERN, located at Zone 18, is used to validate and to test all main components working at cryogenic temperature in the LHC (Large Hadron Collider) before final installation in the machine tunnel. In total about 1300 main dipoles, 400 main quadrupoles, 5 RF-modules, eight 1.8 K refrigeration units will be tested in the coming years.

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We report on the design and layout of the test facility as well as the commissioning and the first 10,000 hours operational experience of the test facility and the 18 kW LHC refrigerator.

INTRODUCTION

The Large Hadron Collider (LHC) is the next accelerator being constructed on the CERN site. The LHC machine will mainly accelerate and collide 7 TeV proton beams but also heavier ions up to lead. It will be installed in the existing 27 km circumference tunnel, about 100 m underground, which was housing the Large Electron Positron Collider (LEP) until 2001. The LHC design is based on superconducting twin-aperture magnets which operate in a superfluid helium bath at 1.9 K. This machine is scheduled to come into operation in the year 2007.

The new 18 kW at 4.5 K refrigerator, part of the refrigeration system for the LHC and installed in Point 18 [1], has been integrated to the existing cryogenic infrastructure in the SM18 building [2,3] to provide the necessary cooling and gas recovery for the largest cryogenic test facility at CERN, hereafter called Zone 18. During the LHC construction,

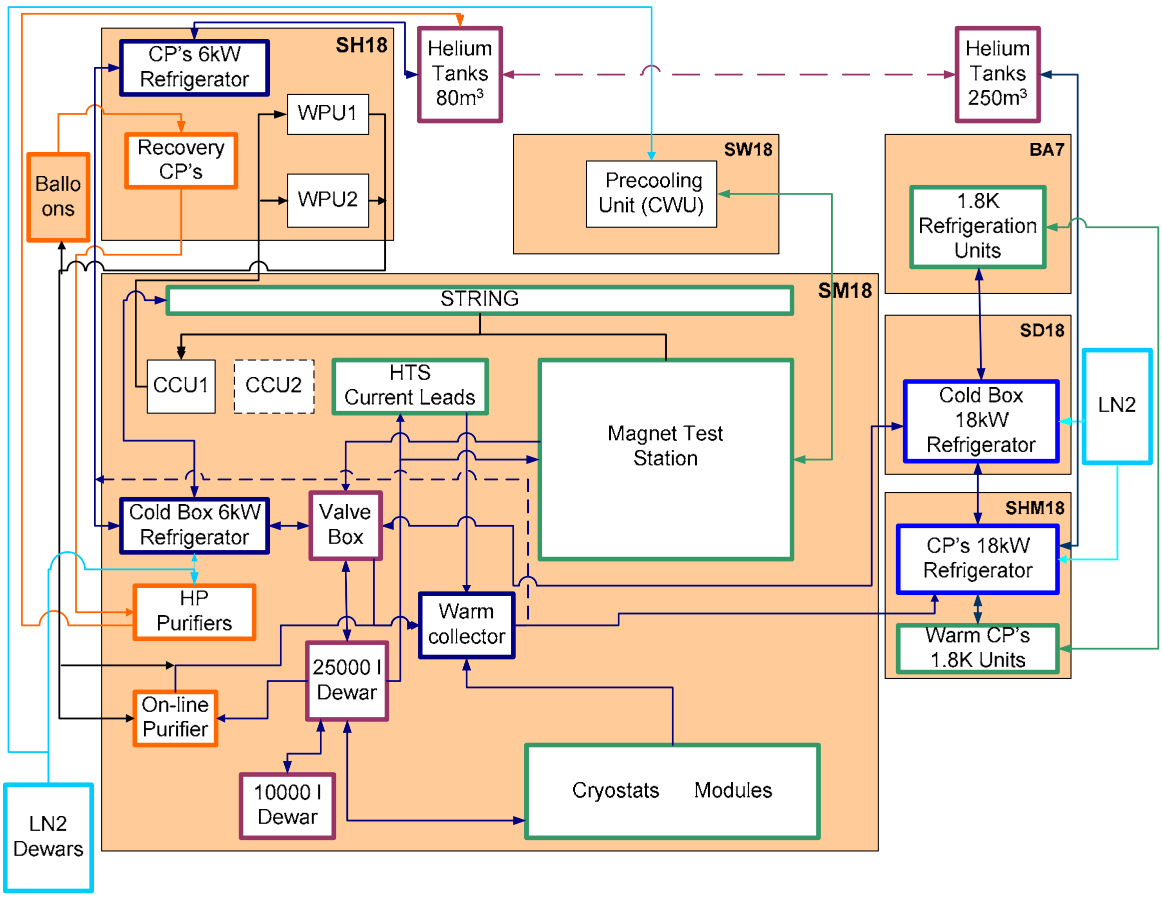

FIGURE 1. Functional diagram of the cryogenic infrastructure of Zone 18 (discontinuous lines indicate redundancy circuits).

this area has been and will be used for magnet cryostating and testing as well as for testing different equipments like the RF-cavity modules, the String experiment [4], prototype HTS current leads [5] and the 1.8 K refrigeration units [6, 7].

GENERAL LAYOUT

The functional layout of the cryogenic infrastructure of Zone 18 is presented in FIGURE 1. Two refrigerators of 6 kW and 18 kW refrigeration capacities at 4.5 K respectively supply liquid helium to the main users via the 25,000 liter dewar located in the main building SM18. Cryogenic valve boxes and distributed warm collectors ensure the complete redundancy of liquid helium distribution as well as cold and warm gas recovery from any of the two refrigerators. Both refrigerators can also directly supply liquid helium to another user.

The 18 kW refrigerator (Air Liquide) is installed in an adjacent building (SD18) and supplies supercritical helium (0.3 MPa, 4.5 K) via a new cryogenic coaxial transfer line (~250 m) to the 25,000 liter dewar and via another cryogenic transfer line to the test station of the 1.8 K refrigeration units in building BA7. It has a maximum liquefaction capacity of 150 g/s with nitrogen precooling and maximum low pressure process flow of 770 g/s. This refrigerator is one of the four new 18 kW at 4.5 K refrigerators foreseen for the LHC machine. It will provide the refrigeration capacity for the Zone 18 testing until 2006 before being connected to the LHC refrigeration system.

The 6 kW refrigerator (Sulzer/Linde) is installed in the main building SM18. A cryogenic valve box and two transfer lines allow to supply the dewar and a second user. It has been used for the String experiments [2, 4] until July 2003. It is foreseen to re-use it for other LHC cryogenic components testing (e.g. Electrical Distribution Box, HTS current lead prototypes) as well as ensuring the redundancy for liquid helium supply and gas recovery for magnet testing. It has a maximum liquefaction capacity of 32 g/s with nitrogen precooling and maximum low pressure process flow of 410 g/s.

In order to lower the helium temperature down to 1.8 K for the magnet test station and the String, a common pumping line connects to a very low pressure pumping system [3]. It is composed of a cold compressor unit (CCU1; one centrifugal compressor), a 30 kW heater and a warm pumping unit (WPU1; three roots in series followed by three rough pumps in parallel) giving a pumping capacity of 18 g/s at 1 kPa. A second warm pumping unit (WPU2) and a 30 kW heater have been installed and used during 2003 for the String. It is foreseen to complete the second pumping system with a second cold compressor unit by 2004 in order to have two fully redundant pumping systems available for the magnet test station.

An on-line low pressure helium purification system (POL) is used to purify the flow coming from the warm pumping units [8]. It has a capacity of 18 g/s and can be directly connected to the low pressure of any of the refrigerators. A full recovery and high pressure purification system is also available to purify impure gas. It is composed of five low pressure balloons of 80 m^3 capacity each, 3 recovery compressors (parallel) of 100 m^3/h capacity each and two high pressure purifiers (parallel) of 200 m^3/h capacity each at 20 MPa.

The gaseous helium storage system is composed of 9 tanks of 80 m^3 at 2 MPa for the 6 kW refrigerator, 12 tanks of 250 m^3 at 2 MPa for the 18 kW refrigerator and 18 bottles of 0.9 m^3 at 20 MPa. The 25,000 liter dewar is used as a liquid helium buffer for the users and it can be complemented by two mobile 10,000 liter dewars. Helium delivery is normally done in liquid form to the dewars (~500 kg/h). It can also be done directly to the 18 kW refrigerator (~300 kg/h) by mixing the liquid helium to the low pressure warm gas at the outlet of the cold box.

Two 50,000 liter dewars supply liquid nitrogen for the magnet station precooling unit (CWU, [9]), the high pressure purifiers and the 6 kW precooler. Two other 50,000 liter dewars are used for the precooler and dryer of the 18 kW refrigerator.

FIRST OPERATION EXPERIENCE

Operation Strategy of Zone 18 Cryogenic Infrastructure

In normal operation the 18 kW refrigerator is connected to the 25,000 liter dewar which supplies the magnet test station (up to 2 magnets per day) and the RF cavities station (1 LHC module per month) with steady-state conditions at 1.9 K and 4.5 K respectively. Main transients are cool-down/warm up for magnets and RF modules and quench recovery for magnets. In addition, the 1.8 K units test station requires a varying liquid helium supply between 50 g/s and 150 g/s (cold return at 20 K). The pumping flow from magnets is directly sent to the low pressure of the refrigerator unless a high level of impurities is detected (more than 15 ppm for more than 15 seconds). In this case, the pumping flow is sent either to the balloons or the POL. In order to ensure a stable low pressure for tests, the cold gas return can be directly sent to the compressor inlet via a

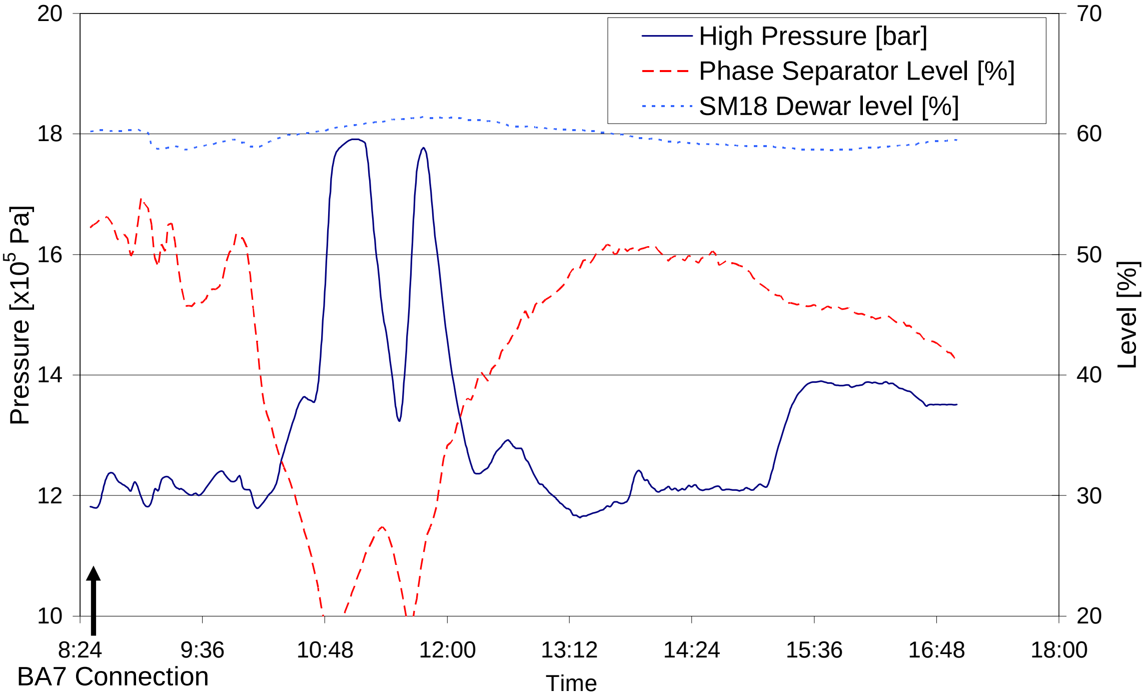

FIGURE 2. Connection and cool-down of the 1.8 K test facility in BA7.

control valve and a 100 kW electrical heater during high cold gas return flow transients (e.g. magnet quench). The 6 kW refrigerator is either supplying the String or in stand-by.

Whenever there is a major problem (pollution, component or utility failure) that stops the 18 kW refrigerator production for more than 1 day, the 6 kW refrigerator takes over and can be cooled down and connected to the dewar in less than 12 hours (1 hour if it is already cold). The recovery of all the cold gas from the users is achieved within 1 hour, thus minimizing helium losses. In case of impurity problems the 18 kW refrigerator can be operational within 5 days (2 days complete warm up at 300 K, 2 days conditioning, 18 hours cool down).

Operation of the New 18 kW Refrigerator

The 18 kW refrigerator was officially accepted in March 2002 after a rather long (2 years) installation and commissioning period to reach specified performance and functionalities [1]. It has been in operation since then, stopping only for a two month winter shut down period for maintenance and consolidation. During 2002 most of the operation tasks were devoted to tuning, configuration and integration of the refrigerator into the Zone 18 cryogenic infrastructure. The various users with their fast transients needed continuous adaptation of the refrigerator capacity and tuning of the turbines and temperature profile of the cold box. This adaptation needed permanent operator interventions and reduced the availability at full refrigeration capacity.

In addition to preventive and corrective maintenance, additional consolidation works took place during the first shut down. On the compressor station the motor-compressors skids were revised with verification of machines fixations, replacement of oil injection valves, modification of shaft seal lubrication piping, blocking of internal volume ratio slide valves for all compressors as well as modification of the low-pressure oil pumps. For the cold box, diagnostics on bearing regulation valves and new reinforced turbines (1 and 2) were installed, the turbine brake heat exchangers circuits were inspected and the cold

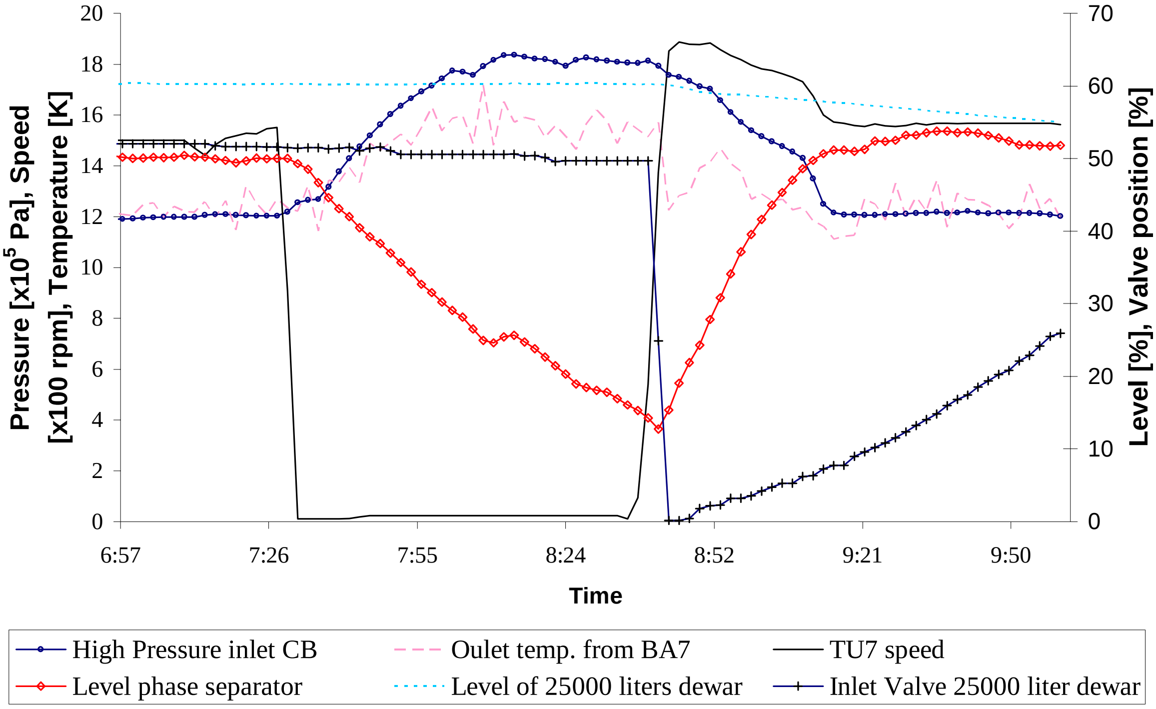

FIGURE 3. Turbine 7 stop and recovery of the phase separator level.

box adsorber regeneration system was modified. Finally, a new valve with smaller flow coefficient for better regulation was installed to feed the 25,000 liter dewar.

Profiting from the experience acquired during the first year of operation, several modifications where implemented in the control system to improve the performance of the refrigerator as function of the different loads and operation conditions. The main modification was the adaptation of the refrigeration capacity to the varying loads by changing the high pressure of the cycle from 1.15 MPa to 2 MPa depending on the power available in the cold box phase separator. In addition, the attenuation of each turbine was adapted to optimize the cold box temperature profile. The results have been extremely satisfactory with the full refrigeration capacity always available for the users during 2003.

FIGURE 2 shows the connection and cooldown of the 1.8 K test facility (BA7) while supplying liquid helium to the 25,000 liter dewar in SM18. Because of the increase of flow to the users the phase separator level decreases to about 40%. As a consequence the setpoint of the high pressure is increased automatically to 1.8 MPa to boost liquefaction. Within 1 hour the phase separator level is recovered while the 25,000 liter dewar level is preserved with a minor fluctuation.

FIGURE 3 shows the recovery from an unstable situation: stop of turbine 7 (20-10 K level), with all users connected. The level of the phase separator decreases to 25 % and the feeding valve of the dewar is closed to avoid transfer of warm gas. The other user is also disturbed as the outlet temperature of BA7 is rising to about 18 K. The high pressure set point increases automatically to give more refrigeration power to recover the level in the phase separator while the turbine is re-started.

HELIUM AND NITROGEN CONSUMPTION

The high number of connection/disconnection and cool down/warm up of users as well as purification of recovered helium, require constant monitoring of inventory and

TABLE 1. Statistics and availability of Zone 18 Refrigerators for 2002 and 2003 (until August).

	18 kW refrigerator (for magnets tests)		6 kW refrigerator (for String)	
	2002	**2003**	**2002**	**2003**
Total hours of liquid helium production in 2002	**6469**	**3544**	**5140**	**3475**
[Performance in %]	[98.9%]	[96.5%]	[97.4%]	[99.9%]
Utilities-stop (electricity, water, compressed air)	29h30 [0.5%]	6h00 [0.2%]	33h36 [0.7%]	2h52 [0.1%]
Cryogenic operation failures (component failures, tuning of new cryoplant, controls)	39h10 [0.6%]	17h27 [0.5%]	28h38 [0.6%]	0h30 [0.0%]
Impurity problems/Regeneration of Cold Box	0h	100h [2.8%]	66h30 [1.3%]	0h
Total "on-call" intervention hours (out of working hours)	220h [4.7%]	165h [3.4%]	45h [0.9%]	60h [1.7%]

losses. During the last two years the average losses have been estimated to 250 kg/week, with purification rates of 800-1000 kg/week. On the basis of monthly helium deliveries and with the big storage capacity of the zone (gaseous and liquid), an average level of 4800 kg is kept to ensure helium supply for all users, even in case of accidental major losses. The mobile dewars allow to supply or receive liquid helium from other CERN zones and a high pressure line ensure gas transfers.

Nitrogen is mainly used for cold box precoolers (6 kW and 18 kW refrigerators), high pressure purifiers and precooling unit for the magnet tests station. The average consumption of liquid nitrogen over the last two year has been less than 6,000 liter/day. The foreseen increase in activity of the magnet test station will increase the consumption up to 20,000 liter/day.

OPERATION AND AVAILABILITY

TABLE 1 summarizes the performance of the two refrigerators of Zone 18 for 2002 and part of 2003. It is clear that the main impact on the users comes from impurity problems, mostly due to continuous accumulation of small amounts of contaminants (leaks in sub-atmospheric pressure circuits, quench, wrong conditioning of opened circuits, malfunctioning of recovery and purification system). The clogging of the 6 kW refrigerator in 2002 occurred on the main exchange column, thus requiring a complete regeneration of the cold box. The clogging of the 18 kW refrigerator in 2003 occurred in the circuit of turbines 1 and 2 (300-80 K cooling) which can normally be compensated by the liquid nitrogen precooler. Unfortunately, an important leak on this circuit to the cold box vacuum prevented to use it and required the full regeneration of the cold box.

Utilities and cryogenic (apart from pollution problems) failures have very low impact on production availability (~ 0.5 % each). For the 6 kW refrigerator the cryogenic failures were mostly due to aging of components and high vibration levels of the compressor station. The 18 kW refrigerator failures were related to design flaws and limited commissioning time. During 2002, main components faults were on oil pumps, compressors shaft seals, and control valves of turbine bearings. Other problems occurred because of the integration to the SM18 infrastructure and not adapted settings of the refrigerator. During 2003, failures were reduced and mainly related to process settings and controls (mainly communication interface problems).

A high number of on-call interventions were required because of the novelty of the installation, its missing functionalities and reduced commissioning time. These interventions are progressively being reduced.

Future goals are the increase of availability for all users and reduction of the intervention time. The automatic adaptation of the refrigerators can be further improved and the redundancy between refrigerators and restart in case of stop can be further optimized. The operation know-how already acquired and the improvement of the diagnostics, procedures and documentation tools, together with a skilled and performing operation team are key elements for the successful operation of this complex installation.

OPERATION AND MAINTENANCE

Based on past experience on subcontracting the exploitation of cryogenic installations at CERN [10, 11], a new operation and maintenance contract started in July 2001. Since then, a dedicated team of 6 operators and 1 operation engineer, supported by the maintenance service of the contract, have been in charge of the exploitation of the Zone 18 cryogenic installations. Main tasks have been assistance to commissioning (for the new 18 kW refrigerator and infrastructure), normal operation and "on-call" interventions, procedures writing and documentation of equipment, corrective maintenance and creation of preventive maintenance plan based on past experience.

On the CERN side, the operation team was composed of 4 FTE's mainly dedicated to commissioning, expert assistance including on-call interventions, coordination and planning of the activities and interface with the users and utility services (electrical power, cooling water, compressed air and controls) as well as management of the exploitation contract. The CERN team has recently been reduced to 2 FTE's thanks to the improvement in operation performance of the zone and reallocation of resources for the LHC cryogenic system commissioning.

CONCLUSION

During the last two years the cryogenic infrastructure of Zone 18 has been upgraded, commissioned, operated and optimized, achieving high levels of flexibility and availability for the users. Integration of a new 18 kW at 4.5 K LHC refrigerator has been successfully completed with intensive participation and professional dedication of the operation teams. The experience during this period has stressed that although operation and maintenance can be outsourced to an external company with satisfactory results, it demands a long adaptation process and requires internal resources for commissioning, consolidation works, assistance and monitoring before going into full delegation of responsibilities.

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