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UPGRADE OF THE CERN CRYOGENIC STATION FOR SUPERFLUID HELIUM TESTING OF PROTOTYPE LHC SUPERCONDUCTING MAGNETS

V. Benda, J.P. Dauvergne, F. Haug, S. Knoops, Ph. Lebrun, F. Momal,
V. Sergo, L. Tavian and B. Vullierme

Abstract

The cryogenic infrastructure of the station for testing LHC prototype superconducting magnets in superfluid helium below 2 K has been upgraded. Liquid nitrogen precooling has permitted to increase the liquefaction capacity of the refrigerator. The addition of cold centrifugal compressors with a pressure ratio of 3:1 has boosted the capacity of the warm pumping unit. To ensure adaptation of the pumping capacity, a heater-and-valve box allows to bypass the cold compressors. This box also comprises a 32 kW electrical heater for warming up the low-pressure gaseous helium before it enters the volumetric warm pumping unit. Possible impurities in the helium returning from the subatmospheric circuits are trapped in a freeze-out helium cleaner. Automatic process control and supervision permit unattended operation and optimal management of the helium inventory.

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INTRODUCTION

In preparation for CERN's new project, the Large Hadron Collider (LHC) [1], we have been operating since 1993 a cryogenic station [2] for testing prototype superconducting magnets in superfluid helium below 2 K. In view of the development of full-scale magnet tests, as well as the operation of a 50-m long prototype magnet string, we have now upgraded the cryogenic infrastructure of the test station.

LIQUID NITROGEN PRECOOLING

A liquid nitrogen precooler was ordered to Air Liquide in 1995 and commissioned at CERN at the beginning of 1996. This device, connected to the 6 kW @ 4.5 K Air Liquide refrigerator, permits to increase the liquefaction capacity from 18 to 37 g/s. To reach this liquefaction capacity, a 1.85 MPa helium flow of 40 g/s coming from the high-pressure side of the refrigerator cycle, is precooled down to 81 K by means of a liquid nitrogen economizer, and reinjected at the corresponding temperature level in the refrigerator. As it is preecooled, this flow is purified in a 260 l "Silicagel" adsorber. Figure 1 shows the flow-scheme of the precooling system, which consumes 700 l/h of liquid nitrogen.

The adsorber is designed for 250-hour autonomy but the overall autonomy is still limited by the main refrigerator adsorber. The impurity level is continuously analyzed at the bottom of the adsorber bed and a 3-hour regeneration cycle is initiated after impurity detection. The "Silicagel" bed is warmed up by gaseous nitrogen flow and cleaned by pumpdown and flushing with pure helium .

The precooler is designed for a maximum mass flow of 80 g/s, which would yield a liquefaction capacity of 75 g/s. To reach this, a supplementary upgrade of the refrigerator is required. In particular, the expansion turbines have to be modified for higher flow and cycle compressors have to be added.

Rapid cooldown and warmup of the superconducting magnet under test are performed by forced flow of gaseous helium under pressure, presently tapped from the cycle compressors of the refrigerator.

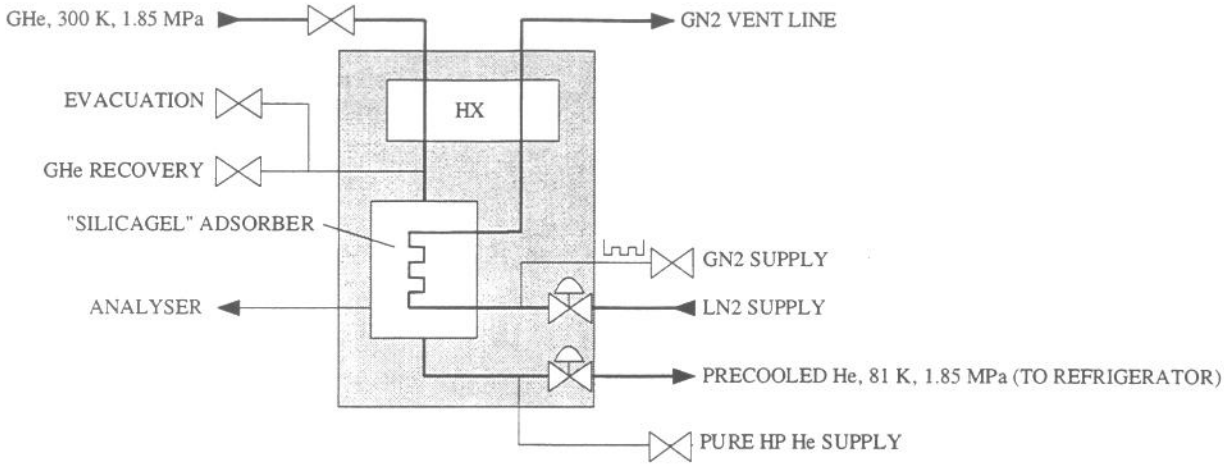

Figure 1 Flow-scheme of the liquid nitrogen precooling unit

PUMPING CAPACITY UPGRADE

Figure 2 shows the upgraded flow scheme of the pumping system which integrates two alternately used cold compressor units (CCU1 and 2), a heater-and-valve box (HVB), the existing warm pumping unit (WPU) and a freeze-out cleaner.

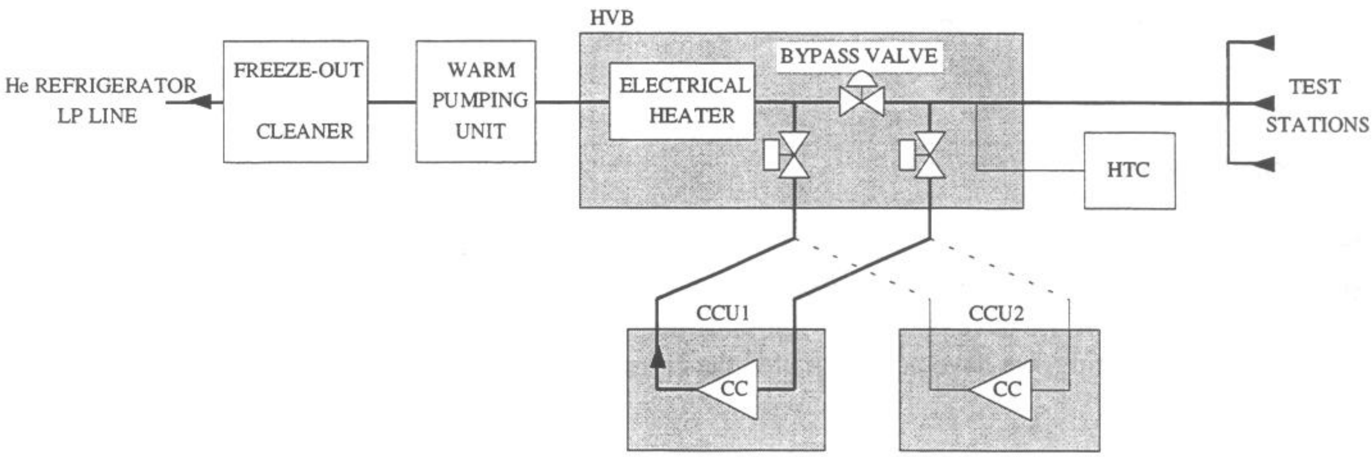

Figure 2 Flow-scheme of the pumping system

Heater-and-valve box

To ensure continuous adaptation of the pumping capacity over the range of flow-rate produced by the user devices, the HVB allows to bypass the low-pressure gaseous helium from the cold compressors. Below 6 g/s the WPU can handle the pumping flow alone; for higher flow, the coupling of one CCU is required. Two DN125 mm isolation valves, connection bayonets and U-tube transfer lines permit to connect alternately either CCU. For CCU commissioning, a dedicated helium test cryostat (HTC) is connected to the HVB to generate adjustable helium flow. This cryostat is also used for testing special 1.8 K components.

The HVB also comprises a low-pressure drop, 32 kW electrical heater [3], for warming up the gaseous helium at 1 to 3 kPa before it enters the WPU. This heater is constituted of two 16 kW cartridges in series. Longitudinal copper plates, with a total exchange surface of 10 m², are heated by coaxial heating elements, brazed under vacuum to the plates for good thermal contact. To avoid electrical breakdown in very-low pressure gaseous helium, the coaxial heating elements are helium-tight and all electrical connections are outside the low-pressure vessel. Figure 3 shows the heater cross-section and Figure 4 the HVB. This heater has to handle large flow variations and due to its big thermal inertia, is controlled by the combination of a PID algorithm and an open loop calculating heating demand from measured flow. The heater is powered by a pulse-width modulation, 3-phase 400 V power converter.

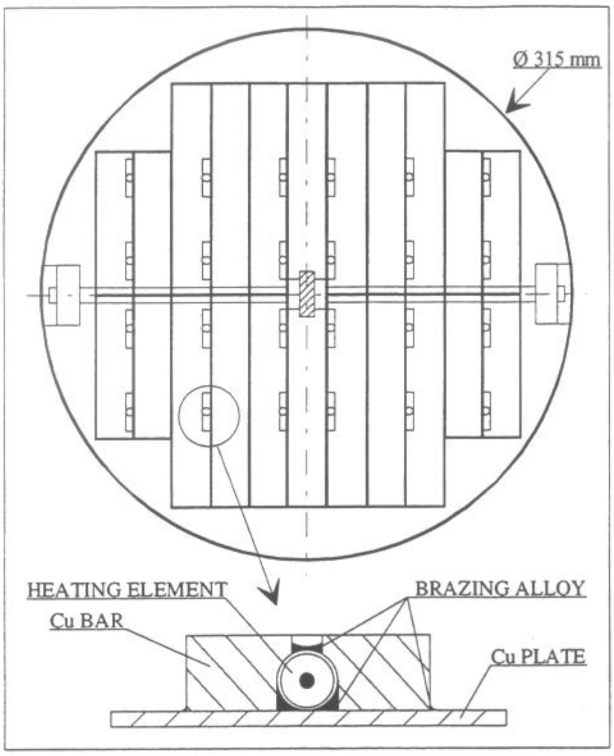

Figure 3 Heater cross-section

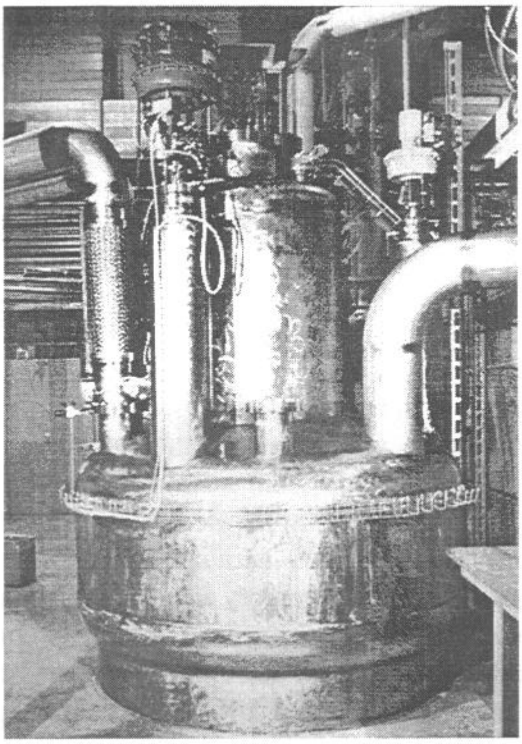

Figure 4 Heater-and-valve box

Cold compressor units

The addition of cold centrifugal compressors with a pressure ratio of 3:1 has boosted the flow capacity of the warm volumetric pumping unit (WPU) from 6 to 18 g/s at 1 kPa suction, thus providing a useful refrigeration capacity of 360 W @ 1.8 K. The CCU supplied by Linde [4] is now commissioned, the other CCU supplied by Air Liquide has run and is being improved.

Freeze-out helium cleaner

Possible impurities in the 18 g/s helium flow returning from the subatmospheric circuits are trapped on-line in a freeze-out cleaner operating at atmospheric pressure, the design of which has been described in reference [5]. Figure 5 shows the flow-scheme of this purifier. The contamination is removed by cryotrapping sequentially in a freeze-out element and in a filter operating at a temperature of 30 K. Cooling of the gas is obtained by injection of liquid helium at a rate of 10 % of the main stream.

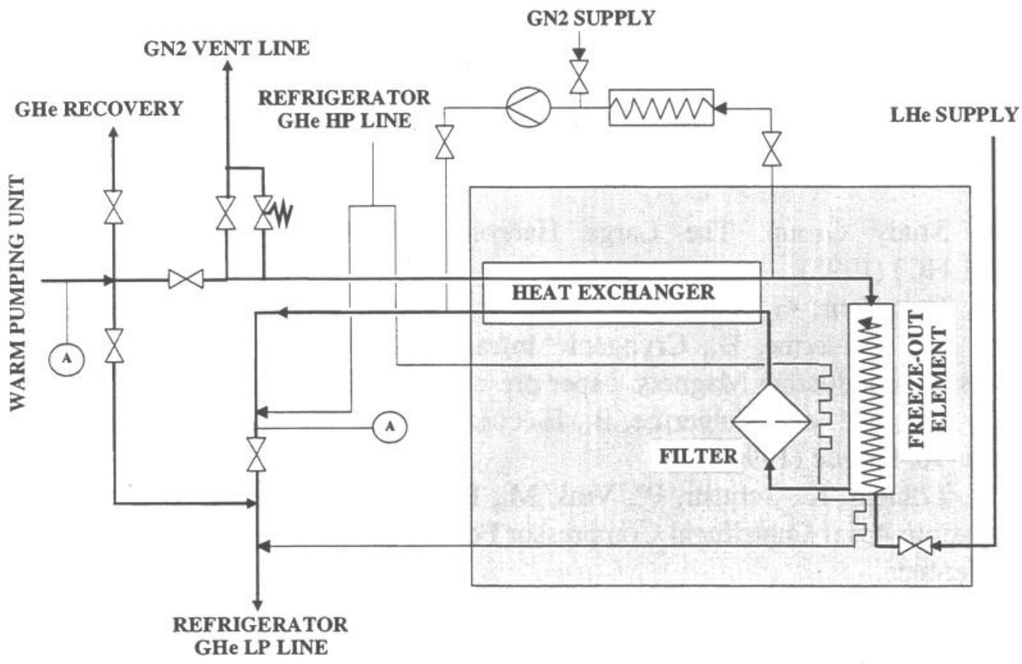

Figure 5 Flow-scheme of the freeze-out cleaner

The system is designed to trap 1 kg of air before saturation, resulting to a minimum autonomy of about 300 hours. Regeneration is initiated when the purifier pressure drop increases up to 15 kPa. The system is warmed up to 90 K and purged with gaseous helium. Such a cleaning takes 30 minutes. High temperature regeneration, with nitrogen circulation, is not automatic and is only used in case of water contamination. During the regeneration, the pumping flow can be directly injected into the suction side of the cycle compressors if the impurity level is acceptable, or else is recovered in gas bags.

PROCESS CONTROL AND SUPERVISION

All additions to the upgraded system are automatically controlled, thus allowing unattended operation. The liquid nitrogen precooler and the freeze-out cleaner are controlled by the existing ABB system of the refrigerator. The cold compressor units have their own Siemens programmable logic controller (PLC). A new "Utility" PLC controls the heater-and-valve box and the liquid helium distribution to the different test stations. An Ethernet® network interconnects the different PLCs, so that the "Utility" PLC is able to manage the helium inventory as well as the instantaneous consumption and availability of fluids and utilities for each test station. Operator interface is constituted by local operator panel and/or by workstations and X-terminals running a FactoryLink® supervision software. In total, 11 PLCs are simultaneously operating, while 3 workstations and 5 X-terminals manage the supervision of the test station area.

CONCLUSION

With a total liquefaction capacity of 37 g/s and with a total pumping flow of 18 g/s at 1 kPa suction which provides a useful refrigeration capacity of 360 W @ 1.8 K and allows the parallel supply of 4 test stations, the cryogenic infrastructure of the test station has now reached the required capacity for testing full-scale magnets and the 50-m long prototype magnet string for the coming years. Comprehensive process control and supervision permits to operate the test stations with minimum staff. The next step will be to install a second 6 kW @ 4.5 K refrigerator available at CERN and to add dedicated circulation compressors for magnet cooldown and warmup.

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