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SPECIFICATION OF EIGHT 2400 W @ 1.8K REFRIGERATION UNITS FOR THE LHC

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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. Taking into account the cryogenic architecture of the LHC and corresponding process design constraints, a reference solution based on a combination of cold centrifugal and warm volumetric compressors was established in 1997. The process and technical requirements expressed in the specification issued in 1998 and the procurement scenario based on pre-series acceptance prior to final series delivery between 2002 and 2004 are presented in this paper.

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1 INTRODUCTION

To complete the cryogenic refrigeration installations for the Large Hadron Collider [1], eight 1.8 K refrigeration units producing the cooling capacity for superconducting magnets, have been specified. Each of these units will be coupled to a 4.5 K refrigerator. In order to validate the process and components, a first unit called "pre-series unit" will be validated by extensive testing at CERN before launching the series unit production. Depending on the technical risk of the proposed solutions, it was envisaged to eventually order and test two pre-series units of two different suppliers. Figure 1 shows the general architecture of the cryogenic installation.

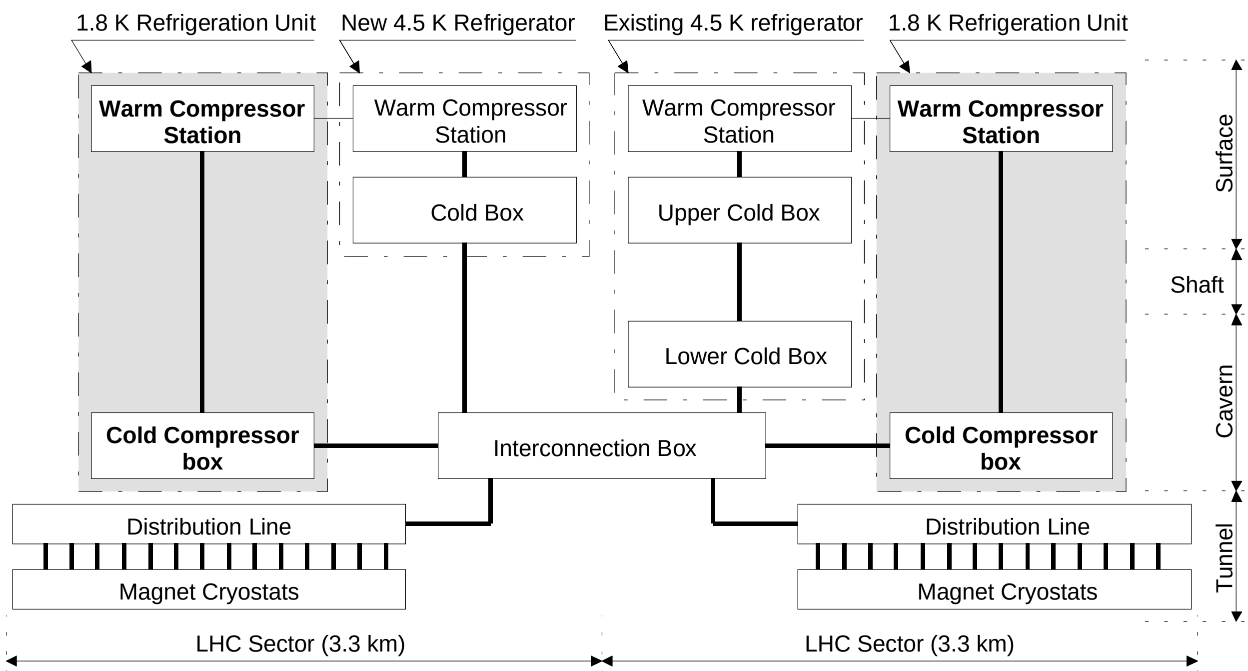
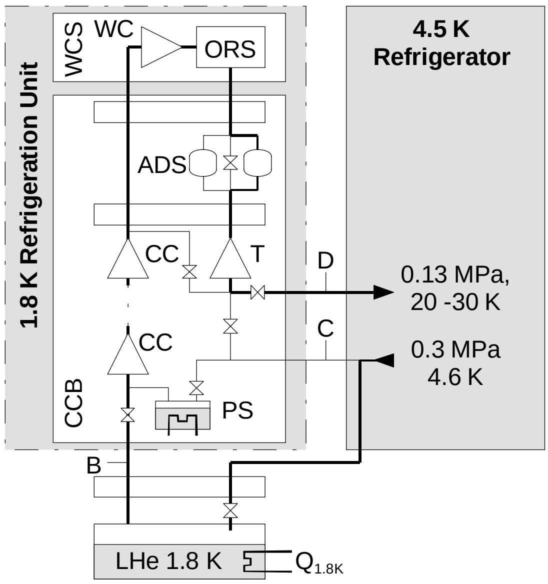


Figure 1 General architecture of a typical cryogenic installation in an even point of LHC

2 INTERFACE CONSTRAINTS AND STEADY STATE OPERATION

A preliminary study on possible upgrades of the existing 4.5 K refrigerators has established two main design constraints. The first constraint concerns the limited entropic load available for the unit; the second one concerns the limited available cold return connection in the low-pressure side of the heat exchanger blocks. These two constraints impose that the capacity induced by the units must be seen by the 4.5 K refrigerators as non-isothermal refrigeration between 4.5 and 20 K. Integral cold compression with direct return to the low-pressure side is no more possible. As a direct consequence, warm compressor (WC), oil removal system (ORS), counter-flow heat exchangers as well as switchable 80 K adsorbers (ADS) are needed. Depending also on the load produced by the cold compressors, active refrigeration using expansion turbine (T) must be added to the cold compressor box (CCB) [2]. Figure 2 shows a typical flow scheme of a 1.8 K refrigeration unit as well as the interface conditions of the different operation modes.

The installed refrigeration capacity is 2400 W at 1.8 K. Due to the high level of dynamic load [3], a ratio of 3 is required for the turndown capability. In steady-state operation, for efficiency consideration and except for the in-situ capacity check mode, no extra heating is allowed in the phase separator (PS).



Modes	Interface conditions $\dot{m}_B$ [g/s]	T_B [K]	P_B [kPa]	$\dot{m}_C$ [g/s]	T_D [K]
Installed	124	4.0	≤ 1.5	≤ 2	≤ 20
Normal	83	4.0	≤ 1.5	≤ 2	≤ 25
Low beam intensity	62	4.2	≤ 1.5	≤ 2	≤ 28
Injection standby	42	4.8	≤ 1.5	≤ 2	≤ 30
Cold standby	37	5.6	≤ 24	≤ 2	≤ 30
Capacity check	0	\	≤ 1.5	126	≤ 20

$\dot{m}_D = \dot{m}_C + \dot{m}_B$

$\dot{m}_C$ limited to 2 g/s for process optimisation

Figure 2 Generic scheme of a 1.8 K refrigeration unit and interface conditions for different steady-state modes

3 TRANSIENT OPERATION MODES

For the transient modes encountered during LHC operation, extra heating is provided for in the phase separator. The corresponding gas production can be used to facilitate the cold compressor adaptation during fast flow variation. This is however not applicable for liquid filling and cooldown of the magnets (see 3.3). Limited magnet quenches should not be seen by the unit whereas full-sector quench should lead to valving off of header B.

3.1. Cooldown and Warmup of the Cold Compressor Box

The cooldown and warmup of the cold compressor box must be possible with the 4.5 K refrigerator in normal operation. The cooldown and warmup must be completed in less than 5 hours. The CCB turbine as well as 40 g/s of helium at 4.5 K coming from interface C could be used for cooldown.

3.2. Pump-down and Specific Cooldown of the Pumping Line

After a unit stop, the cold compressor box must be reconnected to the pumping line (3.3 km, 60 tons) which has a relatively high temperature (up to 40 K) but still a low pressure. The cold compressors are not well adapted to these interface conditions and cold gas produced in the phase separator can be mixed to recover acceptable conditions at the cold compressor inlet. The pump-down time must be less than 2 hours without pumping line coupling (in capacity check) and less than 4 hours with coupling.

3.3. Liquid Filling and Cooldown of Magnets to 1.9 K

The 1.8 K refrigeration unit must also be used to complete the filling of the magnets by condensing the vapour remaining in their helium vessels. During this operation, the pressure at interface B must be kept below 24 kPa. The cooldown of the magnets to 1.9 K must follow and the interface B pressure has to be gradually reduced down to 1.5 kPa. During this transient mode, the 4.5 K refrigerator has no capacity margin and no extra heating is allowed to compensate for pumping flow variation less than 2 g/s per minute.

3.4. Beam Dump and Injection

Beam dump and injection are accompanied by slow current deramping and ramping which give pumping flow variations of ± 6 g/s per minute. The pressure at interface B must remain below 1.7 kPa.

4 SPECIFIC REQUIREMENTS

Concerning standard refrigeration components (valves, instrumentation, expansion turbines, 80 K adsorbers, provision for dryers and process control) the same specification as for the 4.5 K refrigerators [4] is applied. Only specific components and requirements are developed hereafter.

4.1. Cold Compressors

Technology referenced for operation with helium is mandatory [5]. The guaranteed mean time between maintenance of cold compressors must be at least 8000 hours. With respect to the maximum foreseen rotational speed, a margin of 20 % must be possible. A cold compressor cartridge must be exchanged without a complete CCB warmup within 4 hours. The electrical circuits in contact with very-low-pressure helium must have adapted low-voltage power supplies.

4.2. Sub-atmospheric Warm Compressors

Technology based on screw compressors or liquid ring pumps, referenced for operation with helium is mandatory. If several compressors have to be connected in parallel, each one must have the same size and the same suction and discharge pressures. The discharge pressure must remain above the atmospheric pressure in all operation modes.

4.3. Helium Guards

Some components operating below atmospheric pressure and not housed in a vacuum enclosure have to be protected from air inleak by a guard with helium at a pressure above atmospheric. For the warm compressor station, it concerns the instrumentation if not equipped with ISO-KF vacuum flanges, the dynamic seals of valves and compressors if not equipped with bellows or double-garniture with oil injection and all the connection not completely welded nor equipped with O-ring joints. For the cold compressor box, it concerns the safety valves, instrumentation and all the connections and assemblies not completely welded.

5. INTEGRATED COST ESTIMATE FOR ADJUDICATION

For adjudication purpose, CERN has evaluated the bid prices using a formula that takes into account the cost of electricity during ten years of operation. The bidders must provide guaranteed data for the electrical input power of the 3.3 kV supply in the “low intensity” mode (Pg_low), in the “normal” mode (Pg_norm) as well as in “Installed” mode (Pg_inst). In 1998, it was envisaged to adjudicate a first contract for the pre-series to one or two suppliers at a price Ip quoted by the bidder followed, after acceptance of the pre-series, by a second contract for seven series units to only one supplier at a price I7 quoted by the bidder. For the assessment, the total cost C8 for eight units is considered using the formula (1) in which, C and I are in CHF and Pg in kW. The factor 1584 and 792 result from the expected 26400 hours, respectively 13200 hours of operation at a electricity cost of 0.06 CHF per kWh [6].

$$C_8 = I_p + I_7 + 8 \cdot (1584 \cdot Pg\_low + 1584 \cdot Pg\_norm + 792 \cdot Pg\_inst) \quad (1)$$

For the three operating modes, the 3.3 kV power consumption measured during the reception tests will be compared to the guaranteed values of the bids. The difference will result in a compensation payment by CERN (half of the difference) in case of lower consumption than guaranteed, or by the supplier (full difference) if the power consumption exceeds the guaranteed value.

6 TIME SCHEDULE

The time schedule specified for the eight units is as given in Table 1. After the reception test of the pre-series in a surface building, this unit will be used for testing of series cold compressor cartridges and be re-installed in the dedicated cavern after.

	Pre-series	Series 1	Series 2	Series 3	Series 4	Series 5	Series 6	Series 7
Location	Point 1.8	Point 4	Point 8	Point 6	Point 4	Point 8	Point 6	Point 2
Ready for reception	30-Jun 2001	31-Mar 2003	30-Jun 2003	30-Sep 2003	15-Dec 2003	31-Mar 2004	30-Jun 2004	30-Sep 2004
Re-installation date	30-Apr 2005	/	/	/	/	/	/	/

Table 1 Time schedule for the 1.8 K refrigeration units

7 CONCLUSION

Following the specification for the 1.8 K refrigeration units, CERN received two offers in October 1998. After the evaluation of the offers which completely fulfilled the technical requirements, it was decided to split the supply in two. Consequently two contracts for the supply of one pre-series unit each followed after successful reception by a contract for the supply of three series units, were signed with Air Liquide (France) [7] and a consortium between IHI (Japan) and Linde Kryotechnik AG (Switzerland) [8]. The contract with the consortium will be funded by the Japanese contribution to the LHC project. In case of failure during the pre-series phase of one of the suppliers, option for four additional series units have been negotiated. Despite this split, the overall requirements of the technical specification are preserved and both firms are motivated and engaged to supply efficient and reliable equipment.

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