THE LOCAL HELIUM COMPOUND TRANSFER LINES FOR THE LARGE HADRON COLLIDER CRYOGENIC SYSTEM

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Abstract

The cryogenic system for the Large Hadron Collider (LHC) under construction at CERN will include twelve new local helium transfer lines distributed among five LHC points in underground caverns. These lines, being manufactured and installed by industry, will connect the cold boxes of the 4.5-K refrigerators and the 1.8-K refrigeration units to the cryogenic interconnection boxes. The lines have a maximum of 30-m length and may possess either small or large re-distribution units to allow connection to the interface ports. Due to space restrictions the lines may have complex routings and require several elbowed sections.

The lines consist of a vacuum jacket, a thermal shield and either three or four helium process pipes. Specific internal and external supporting and compensation systems were designed for each line to allow for thermal contraction of the process pipes (or vacuum jacket, in case of a break in the insulation vacuum) and to minimise the forces applied to the interface equipment. Whenever possible, flexible hoses were used instead of bellows to allow for thermal compensation of the process pipes. If necessary, compensation units were integrated in the vacuum jacket. The thermal design was performed to fulfil the specified heat-load budget.

This paper presents the main technical design choices for the lines together with their expected performance.

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ABSTRACT

The cryogenic system for the Large Hadron Collider (LHC) under construction at CERN will include twelve new local helium transfer lines distributed among five LHC points in underground caverns. These lines, being manufactured and installed by industry, will connect the cold boxes of the 4.5-K refrigerators and the 1.8-K refrigeration units to the cryogenic interconnection boxes. The lines have a maximum of 30-m length and may possess either small or large re-distribution units to allow connection to the interface ports. Due to space restrictions the lines may have complex routings and require several elbowed sections.

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KEYWORDS: Distribution, Transfer line, Thermal contraction

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INTRODUCTION

The cryogenic distribution system of the LHC is centralised in five cryogenic interconnection boxes situated in the underground caverns. These boxes provide at each of the five-feed points the connection between the different cryogenic sub-systems, which include the 4.5-K refrigerator lower cold boxes and the 1.8-K refrigerator units [1]. To establish the connection between these different cryogenic equipments twelve local distribution lines (QUL) are required with lengths between 5-m and 30-m.

The QUL lines are divided into two types: the QULA lines that connect the interconnection boxes to the 4.5-K refrigerator cold boxes and the QULC (A and B) lines which connect the interconnection boxes to the 1.8-K refrigeration units.

The geometry of each QUL line depends on the position (and type) of its interface equipment and mainly on the environmental constraints. The presence of other equipments and structures imply the partition of lines into several sections with elbow configurations for most parts of the QUL lines as presented in FIGURE 1. In addition, the QULC lines may require internal re-distribution of the process pipes while the QULA lines require the existence of large re-distribution units to allow specific rigid branch connections to the 4.5-K refrigerator cold boxes ports. In these regions the diameter of the vacuum jacket is increased.

The QUL lines are composed of a vacuum jacket inside which run three or four internal process pipes (QULC and QULA lines, respectively). All process pipes and vacuum jacket are manufactured in stainless steel AISI 304L. Their design data is presented in TABLE 1.

FIGURE 1. Cavern environment with all cryogenic equipment and distribution lines (LHC point 8).

TABLE 1. Process pipes nominal and design conditions

Line	Process pipes (or vacuum jacket)	Nominal temperature [K]	Nominal pressure [MPa]	Design pressure [MPa]	Main outer diameter [mm]
QULA	C (supply)	4.6	0.3	2	104
	D (return)	20	0.13	2	154
	E (supply)	50	1.95	2.2	84
	F (return)	75	1.8	2.2	84
	Y (vacuum jacket)	300	vacuum	0.14	610
QULC	B (return)	3.8-4.2	0.0016	0.4	255
	C (supply)	4.6	0.3	2	48.3
	D (return)	20	0.13	2	88.9
	Y (vacuum jacket)	300	vacuum	0.14	506

To avoid direct thermal radiation loads from 300 K to the nominal temperatures, all QUL lines are equipped with an aluminium thermal shield installed between the vacuum jacket and the internal pipes bundle. The shield is thermalised by pipe F in the case of the QULA lines and pipe D in the case of the QULC lines. The thermalisation is made by means of two aluminium half-shell extruded profiles riveted to the shield and bolted around the applicable pipe (see FIGURE 2). The rivets are installed with a clearance which allows a relative contraction between the shield and the process pipe. An exception is made in the QULA branches connected to the 4.5 K refrigerator cold box where no shield exists. The process pipes are wrapped individually with 10 layers of multi-layer insulation (MLI) composed of double-aluminised Mylar and plain white polyester netting. The thermal shield and process pipes in the QULA line branches are wrapped with 30 layers of MLI.

FIGURE 2. Typical cross-sections of the QUL lines.

TABLE 2. Maximum admissible heat loads on the QUL process pipes

Heat loads [W/m]	Pipe B At 3.8-4.2 K	Pipe C At 4.6 K	Pipe D At 20 K	Pipe E At 50 K	Pipe F At 75 K
QULA	N.A.	0.5	1.0	1.0	4.0
QULC	0.5	0.5	4.0	N.A.	N.A.

TECHNICAL DESIGN

The QUL lines are built to specific requirements in terms of mechanical and thermal design. In what concerns the mechanical design, the forces applied at the interface pipes and vacuum jacket must be limited to low axial values (maximum 5 kN) and no transverse loads or moments. In addition, both internal and external supports were designed to withstand the loads induced during pressure tests and nominal operation. The thermal contractions (or expansions) are handled by means of dedicated braided flexible-hoses or compensation units (bellows) to keep the overall loads and stresses within acceptable values.

The maximum heat loads acceptable on each process pipe are presented in TABLE 2. The heat loads were estimated for each process pipe and compared with the admissible values for selection of the best internal design solution.

The QUL lines do not possess dedicated instrumentation (nor the interface boxes) to allow evaluating the thermal loads into each process pipe. For this purpose, only a qualitative inspection will be performed of the vacuum jacket during commissioning to detect possible cold spots.

INTERNAL SUPPORTS AND COMPENSATION SYSTEM

The internal supports are either fixed or chariot (sliding) spacers. These spacers are basically composed of G10 woven glass-epoxy laminate plates to which are glued G10 glass-epoxy filament-wound tubes inside which the process pipes run. The choice of G10 was made to minimise the thermal loads by heat conduction. Whenever possible copper braids are also used to thermalise the G10 plates via the thermal shield. Fixing rings are used to anchor the G10 tubes to the process pipes or the G10 spacer assembly to the vacuum jacket when required.

The fixed spacers are anchored to the vacuum jacket and withstand the lateral forces induced by flexible-hose displacements and the bellows axial forces due to internal pressure. All process pipes are fixed to these spacers and no displacements are allowed.

The chariot spacers withstand the lateral forces induced by flexible-hose displacements and guide the process pipes in the long straight sections (to minimise misalignments and instabilities, which may induce buckling). Pipe D (or B, for QULC lines) is fixed to the G10 plate while the remaining pipes can slide in the G10 tubes. A system of sliding G10 rods bound to the G10 plate and equipped with stainless-steel wheels on both extremities, allows the independent movement of pipe D (or B) in the axial direction.

The different designs of the internal spacers are shown in FIGURE 3. Both types of spacers have been tested to determine their rupture limits to different types of loads and were improved when necessary to increase these limits.

FIGURE 3. Internal supports assemblies.

Other spacers exist to keep the pipe bundles together inside the vacuum jacket. They consist of simple thin G10 plates with adequate openings to increase the thermal path length and therefore minimise the heat transfer by conduction between the pipes at different temperatures.

The optimum type, position and quantity of internal supports, as well as the compensation system for each QUL line were obtained via an iterative process. Dedicated calculations were performed for different configurations to determine the loads applied on the internal supports and interfaces, Von Mises equivalent stresses, and internal displacements observed on the overall process pipes. While for some lines (e.g., QULCB at P8 and QULA at P2) bellows were used due to the existence of long straight sections, for other lines (e.g., QULA P8), due to their elbowed geometry and short straight sections, flexible hoses were enough to guarantee that the thermal contraction loads and stresses were within acceptable limits for the process pipes and spacers. In a particular case (QULCA P2) long curved flexible hoses will be used to compensate for the thermal contractions in a straight line (overall length of 4.5-m). This solution was chosen instead of bellows to minimise the loads applied on the interfaces.

EXTERNAL SUPPORTS AND COMPENSATION SYSTEM

The external supports are composed of sliding anti-twist frames (placed before the interfaces ports, see FIGURE 4) and weight supports, either rigid or equipped with springs. The first ones ensure that only axial forces are transferred into the interface equipment. The weight supports constrain the vertical displacement of the vacuum jacket due to weight and allow a certain vertical displacement (a function of the spring rate) in case of an accidental cool-down of the vacuum jacket.

FIGURE 4. Sliding anti-twist frames installed on the QULCB P8 line.

The external supports configuration and compensation system was designed using the same method as for the internal process pipes. For some lines (e.g., QULA P2) the use of external bellows was required to minimise the overall stresses and loads in case of an accidental break of the insulation vacuum. However, for other lines (e.g., QULA P8 and QULCB P8), the vacuum jacket deforms without giving rise to high loads and stresses. In these cases no dedicated compensation elements were used.

The external bellows used in the QUL lines are blocked against compression by means of reinforced bars which withstand the atmospheric pressure background effect (see FIGURE 5) but are left free to expand in order to allow thermal compensation in case of an accidental cool-down of the vacuum jacket (due to a break of the insulation vacuum).

FIGURE 5. Blocking system against compression on external bellows.

ACCEPTANCE AND COMMISSIONING TESTS

Once installed, the QUL lines undergo two phases of tests.

Phase 1 - Acceptance Testing

The vacuum jacket is pumped-down to reach an insulation vacuum pressure lower than 10^{-1} Pa when warm. The internal process pipes are subject to a global pressure test at 1.25 times the design pressure (to validate their mechanical strength) followed by a helium leak tightness test of the process pipes and vacuum jacket to guarantee that leaks are below 1×10^{-9} Pa.m³/s and 1×10^{-8} Pa.m³/s, respectively. Since the QUL lines will operate under a static vacuum this last requirement must be strictly fulfilled.

Phase 2 – Cold Commissioning (Cool-down to Nominal Conditions and Warm-up [2])

Helium gas at cold temperature (about 5 K) will circulate from pipe C to B and/or D via by-passes on the interface boxes. Helium gas at 50 K will circulate from pipe E to F in the case of the QULA lines. Once stable conditions are reached the insulation vacuum will be monitored to verify if it remains stable. The vacuum jacket will be inspected to detect the existence of possible cold spots (which indicate the presence of high heat loads) and the external supports will be controlled to verify if any deformations occurred during this phase. The warm-up will be performed by circulating helium gas at ambient temperature in all process pipes.

CONCLUSIONS

The twelve local helium transfer lines specified by CERN are being manufactured by A.S. Scientific Products Ltd., UK. The design of eleven lines is completed. Four lines have been already installed and successfully accepted (two among them were already commissioned) while three are currently being fabricated. The last QUL line is foreseen to be installed and tested by the end of 2006.

The internal and external supporting and compensation system of the QUL lines is particular and different for each line. It was designed to respect both mechanical and thermal requirements as well as to minimise the overall costs.

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