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THE COMPOUND CRYOGENIC DISTRIBUTION LINE FOR THE LHC: STATUS AND PROSPECTS

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Abstract

After a pre-series phase qualifying the design of three European firms, CERN adjudicated end of 2001 one contract for the manufacturing and installation of the cryogenic distribution line (QRL) for the LHC (Large Hadron Collider). Each of the eight ~3.2 km QRL sectors is feeding helium at different temperatures and pressures to the local cooling loops of the strings of superconducting magnets operating in superfluid helium below 2 K. With an overall length of 25.8 km the QRL has a very critical cost to performance ratio. We present a project overview describing all phases, status and schedule.

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The compound cryogenic distribution line for the LHC: status and prospects

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After a pre-series phase qualifying the design of three European firms, CERN adjudicated end of 2001 one contract for the manufacturing and installation of the cryogenic distribution line (QRL) for the LHC (Large Hadron Collider). Each of the eight ~3.2 km QRL sectors is feeding helium at different temperatures and pressures to the local cooling loops of the strings of superconducting magnets operating in superfluid helium below 2 K. With an overall length of 25.8 km the QRL has a very critical cost to performance ratio. We present a project overview describing all phases, status and schedule.

LAYOUT

The LHC cryogenic distribution scheme [1] for each of the eight sectors, individually served by a refrigeration plant, is based on a separate cryogenic distribution line (QRL) feeding helium at different temperatures and pressures to the elementary cooling loops of the magnet cryostats and other cryogenic users [2]. A QRL sector is a continuous cryostat of ~3.2 km length without any header sectorisation, but divided into nine vacuum sub-sectors. Each LHC sector is composed of different machine sections, namely Long Straight Sections (LSS), Dispersion Suppressors (DS) and arc, the latter constituting about ¾ of the total sector length (see Figure 1). The QRL, following the LHC lattice, is a repetitive pattern of pipe modules (~100 m) and service modules (~6.6 m), which link the QRL once at every full cell to the magnet cryostats (see Figure 2). The arc is made of 22 identical cells, each of 106.9 m length. The DS is made up of four cells of QRL cell length varying from 79 m to 93 m. The LHC lattice in each LSS is very particular in layout with QRL cell lengths from about 10 m to 115 m. A QRL sector starts at a cryogenic interconnection box (QUI), which is the central connecting element between all parts of the cryogenic system at one feeding point.

The QRL comprises three headers (see Figure 1) at 4-20 K, namely B, C and D. Header C (Ø 100 mm) distributes supercritical helium at 4.6 K and 0.3 MPa for cooling the beam screen circuits and heat intercepts, for initial filling of the magnet cryostats and for supplying the 1.9 K cooling loop.

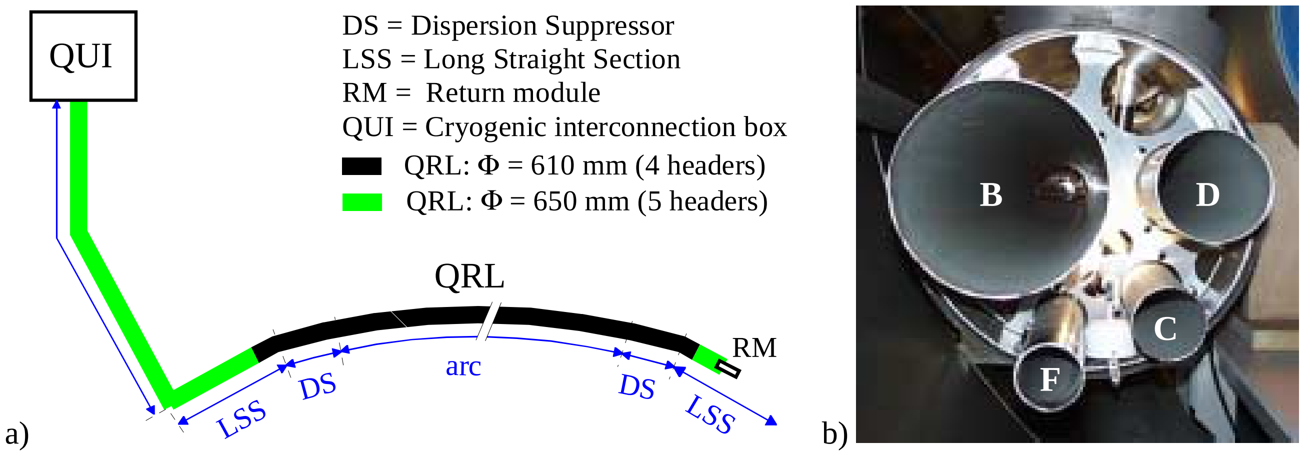

Figure 1 QRL: a) sector layout of a typical feeding point, b) cross-section (mock-up)

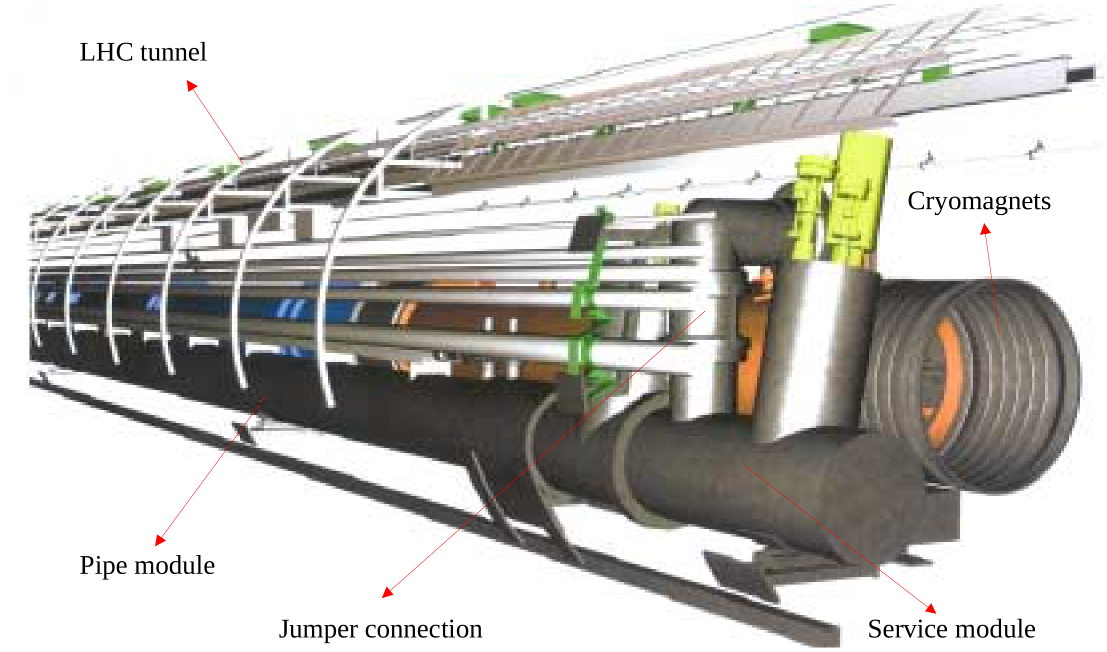

Figure 2 Perspective view of LHC tunnel

The pumping return header B (Ø 267 mm) ensures 1.6 kPa in the bayonet heat exchangers of the magnet cold masses filled with saturated superfluid helium. By passing through the subcooling heat exchangers inside each service module, the pumped gas is warmed up to 4 K, the nominal temperature of header B. The return header D (Ø 150 mm) nominally operating at 20 K and 0.13 MPa, also serves as cold recovery line in case of a magnet quench. Finally, gaseous helium at 50 to 75 K will cool the thermal shields of the QRL and the LHC magnet cryostats. Inside the arc and DS the supply header E (Ø 80 mm, nominal pressure 1.95 MPa) is an integral part of the cryomagnet string, while the return header F (Ø 80 mm, nominal pressure 1.8 MPa) is always part of the QRL (see Figure 1).

A service module houses the subcooling heat exchanger, all cryogenic control valves for the local cooling loops (typically 4-5), one or two quench relief valves as well as the necessary monitoring instrumentation. The so-called jumper connection, part of the service module, houses up to nine tappings (diameter 10 mm to 80 mm) to and from the magnet cryostats and a transverse vacuum barrier separating the QRL from the magnet string vacuum systems. All interconnecting pipes as well as the vacuum jacket are equipped with flexible elements to minimise forces introduced by the QRL to the precisely aligned cryomagnets and to allow re-alignment of the magnet strings without displacement of the QRL. Due to different cryogenic users and flow-scheme peculiarities, 38 different types of service modules are required. Most of them are located inside the LSS. This number increased from 26 to 38 following the evolution of the LHC machine optics between 1997 and 2002. The originally foreseen cryogenic flowmeters monitoring the individual consumption of each user were suppressed due to LHC budget constraints.

A standard pipe module consists of 8 straight pipe elements (~11.3 m), one fixed point element (~6.6 m) located in the centre and compensation units. Different QRL cell lengths and routing singularities (e.g. departure from the LHC tunnel towards the QUI located inside a cavern) will be accommodated by special pipe elements of non-standard length or an elbow.

PROJECT STRUCTURE

The QRL project started in 1995 with the decision to have a separate cryogenic distribution line instead of the cryogenic distribution as an integral part of the cryomagnet string. This decision was driven, on one hand by limiting the cryomagnet outer dimension with respect to the existing tunnel as well as the interconnect complexity, and on the other hand by simplifying commissioning as well as operation and maintenance by separating the cryogenic distribution system from the cryomagnet strings.

Table 1 QRL inventory

Service modules	Arc/DS: 208 (7 types, 86 x type QRLAA, 88 x type QRLAB)
	LSS: 102 (31 types, number of units per type up to 17)
	Valves: ~ 1450 cryogenic control and 320 quench relief valves
	Subcooling heat exchangers: 223 (3 different types)
	Instrumentation: ~2130 thermometers, ~340 pressure transducers, 8 level gauges, 34 heaters
	Jumper connection: ~4000 cryogenic flexible hoses for interconnecting pipes
Pipe modules	Standard cell: 8 standard straight pipe elements (~11.3 m) and 1 fixed point element (~6.6 m)
	Elements: total ~2000, of which ~1650 standard straight pipe elements
	~2300 cryogenic bellows for longitudinal compensation
	Some 14000 cryogenic interconnect welds to be done in the tunnel

Feasibility study

The following in-house feasibility study emphasized the main layout challenges such as very low heat inleak values per unit length, limited space available in the existing tunnel and element standardization to optimize the very critical cost-to-performance ratio. During this phase the originally foreseen header A for subcooled liquid helium distribution was suppressed. As a consequence, the subcooled liquid helium had to be produced locally in each service module by dedicated heat exchangers. The original length of 53 m for the local magnet cooling loops could be doubled and therefore every second jumper connection suppressed [1]. The functional specification dated end of 1997 was based on CERN's conceptual design letting the design responsibility with the potential suppliers. Following competitive tendering, CERN adjudicated in 1998 contracts for a 112 m long pre-series test cell to Air Liquide (FR), Linde-Babcock (DE) and the HELU consortium [Alstom (CH, leader), Kraftanlagen (DE), Messer-Griesheim (DE), Nexans (DE) and Nordon (FR)].

Pre-series test cell

The aim of the pre-series test cell was to qualify the design and to verify the thermal and mechanical performance, while maintaining technical and commercial competition for the final tendering in 2001. Using a dedicated test set-up, designed and built at CERN [3], the pre-series test cells, installed by the respective suppliers, were extensively tested at CERN in 2000/2001 including heat inleak measurements at 4 K before and after thermal cycling [4]. The suppliers were requested to design the pre-series test cell as close as possible to the final concept as concerns major components, considering the subsequent series production. Thereby the test cells were also used to qualify the manufacturing process and to validate installation and quality control procedures. All three designs have been qualified for the QRL series re-tendering in 2001.

Final QRL

Following a competitive final tendering CERN adjudicated end of 2001 the QRL contract to Air Liquide (FR). With a total length of about 25.8 km, the QRL is a largely modular set-up of pipe and service modules allowing a high degree of standardisation and consequently series production of various elements. Industrial series production of highly reliable cryogenic modules with unprecedented low heat inleak (headers B, C and D: 537 W to 593 W per sector) for the lowest price per meter ever achieved is the challenge of this project.

Following the detailed design for all standard and special elements of the first sector as well as the set-up and qualification of the production lines, manufacturing will start in 2003 and installation of the first QRL sector will begin in June 2003. Manufacturing and installation need to be synchronised to optimise the necessary stock at the lowest possible level.

To verify the quality of series manufacturing with respect to the pre-series test cell performance, an option is foreseen to have a series verification cell tested at CERN as done with the pre-series test cell.

This phase is structured by a sequence of reviews for each sector to ensure the correct and complete status as well as implementation of feedback from other phases or sectors before starting the next major steps (design, manufacturing, delivery, installation). A first review is established to complete as well as to confirm all detailed layout information by CERN for the final design (e.g. special elements or integration singularities) of the respective sector. The aim of the second review is to verify the documentation status necessary for production as well as the correct implementation of all corrective measures identified during previous steps. During production several mandatory inspection points are foreseen to verify e.g. the proper functioning of all instrumentation before closing a module. As a final step before the delivery to CERN, the conformity of the items, including accompanying documentation, with the specification (e.g. dimensional check) and the correct status ("closed") of all related actions will be checked. The aim of the installation readiness review is to complete, if necessary as well as to confirm all detailed information (e.g. survey information) as well as to verify that all co-ordination tasks (e.g. for transport and handling) in between the contractor and CERN are done. Each sector installation will be followed-up by a technical de-briefing to guarantee adequate feedback for the next sectors.

Special emphasis is given to quality assurance and control by implementing dedicated procedures at the suppliers as well as at CERN following the LHC Quality Assurance Plan. Examples are degressive control of automatic welding in the tunnel or dedicated traceability tools and procedures.

OVERALL INSTALLATION PLANNING

Following the availability of the tunnel, after completion of civil engineering works and general service installation, the major milestones for the QRL planning imposed by the overall LHC planning are: (a) 1st QRL sector to be installed before end of 2003 and (b) last QRL sector installed and commissioned before end of 2005. The sequence of QRL sector installation is according to the LHC planning.

The QRL installation planning considers a minimum time of 14 months between signature of contract and start of installation, avoids parallel installation at the beginning and minimizes parallel installation later. It also evades parallel reception testing due to limited manpower.

The installation period per sector (~3.2 km) is 19 weeks (21 weeks for the first two sectors) with previous access (8 weeks) for preparation works such as survey activities or installation of external supports. The installation and pre-commissioning (vacuum, instrumentation…) will be done according to the nine vacuum sub-sectors, of which two will be installed in parallel. Afterwards three weeks are scheduled for the sector commissioning followed by the reception phase during eight weeks (12 weeks for the first sector) with sector performance testing at 4 K. Installation of subsequent sectors is overlapping by ten weeks, except for the first three sectors. After having completed the installation of a QRL sector, magnet installation will start in parallel to QRL reception from the third sector onwards.

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