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MANUFACTURING AND INSTALLATION OF THE COMPOUND CRYOGENIC DISTRIBUTION LINE FOR THE LARGE HADRON COLLIDER

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Abstract

The Large Hadron Collider (LHC) [1] currently under construction at CERN will make use of superconducting magnets operating in superfluid helium below 2 K. A compound cryogenic distribution line (QRL) will feed with helium at different temperatures and pressures the local elementary cooling loops in the cryomagnet strings. Low heat inleak to all temperature levels is essential for the overall LHC cryogenic performance. Following a competitive tendering, CERN adjudicated in 2001 the contract for the series line to Air Liquide (France). This paper recalls the main features of the technical specification and shows the project status. The basic choices and achievements for the industrialization phase of the series production are also presented, as well as the installation issues and status.

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The Large Hadron Collider (LHC) [1] currently under construction at CERN will make use of superconducting magnets operating in superfluid helium below 2 K. A compound cryogenic distribution line (QRL) will feed with helium at different temperatures and pressures the local elementary cooling loops in the cryomagnet strings. Low heat inleak to all temperature levels is essential for the overall LHC cryogenic performance. Following a competitive tendering, CERN adjudicated in 2001 the contract for the series line to Air Liquide (France). This paper recalls the main features of the technical specification and shows the project status. The basic choices and achievements for the industrialization phase of the series production are also presented, as well as the installation issues and status.

MAIN TECHNICAL SPECIFICATION AND DESIGN

The QRL [2] is composed of 8 sectors of 3.1 to 3.3 km length, each installed in the 27-km circumference tunnel of the Large Hadron Collider. The QRL is a repetitive pattern of pipe modules and service modules equipped with cryogenic valves and instrumentation and interconnected to the superconducting magnets at every 106.90 m. The QRL houses four (or five) headers each one of them with helium supply or recovery functions and with temperatures ranging from 4 K to 75 K. Each sector starts at a cryogenic interconnection box (QUI) with the junction region and ends with a return module (see Figure 1). The QRL has a polygonal structure to follow the curvature of the tunnel. In the junction regions, complex 3D line geometries, with lengths from 15 m to 70 m, are required due to surrounding environment constraints (see Figure 2). The internal support system is composed of a fixed point each 53.5 m (installed on a service module and fixed point or vacuum barrier element) and several sliding supports. Internal bellows are installed between each internal fixed point. The external fixed points are included on each QRL element followed by a sliding support and external bellows are installed on each interconnection between two fixed points to compensate for thermal contraction in case of accidental loss of insulation vacuum. In non-standard regions the support layout is specific and the thermal compensation is made, whenever possible, by means of flexible hoses. Reinforced supports are installed at the QRL extremities to withstand the force due to the pressure end effect.

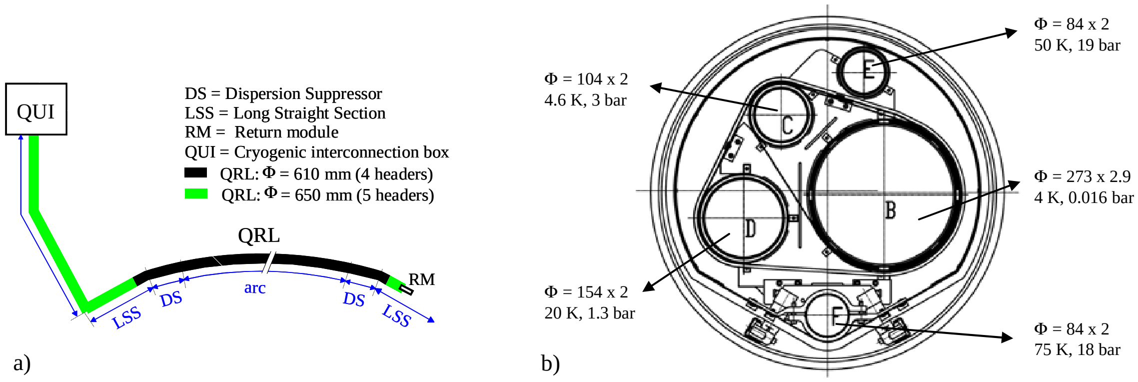

Figure 1 QRL sector layout

All main QRL elements, inner headers and internal fixed points are fabricated in austenitic stainless steel AISI 304 L except for the pipe element vacuum jackets, which are in carbon steel, and the inner headers of the cryogenic extensions which are in Invar®. Several engineering challenges were overcome throughout the different project phases: the junction region of the first sector had to be re-designed based on a detailed mechanical analysis and the corresponding elements repaired. Following this problem all junction regions were analyzed and designed based on mechanical calculations. Some internal sliding support components had to be reinforced and the composite material used (Neonite®) was fabricated with long fibers instead of short ones to increase the resistance to impacts. The external supports were also reinforced and re-designed following calculations.

INDUSTRIALISATION PHASE

Each sector is composed of 238 straight pipe elements (90 % are standard elements), 30 vacuum barrier and fixed point elements, 38 service modules (of 15 different types), 10 singularities such as steps and elbows. The series productions have been subcontracted to 5 European industrial companies, each one dedicated to particular types of modules: a joint venture Air Liquide / 2C (France) for the standard pipe elements, Simic (Italy) for specific and standard service modules, FCM (Spain) for standard service modules, Tuboplan (Portugal) for specific pipe elements, vacuum barrier and fixed point elements, and singularities, Air Liquide DTA (France) for standard service modules and specific double-jumper service modules.

Figure 2: Typical QRL elements and junction region layout

The supply chain of components required for the productions was managed by Air Liquide, purchasing from various multi-sources and shipping to the different European subcontractors. The production was interrupted in the summer 2004 after about one year following serious technical and quality problems (e.g. faulty components and poor quality of welds) discovered on a number of elements equivalent to two sectors (about 500 pipe elements, 80 service modules and 90 vacuum barrier and fixed point elements). During the interruption, all procedures for the different manufacturing phases (e.g. welding, super-insulation wrapping, pressure and leak tests) were revised by Air Liquide in close collaboration with CERN. The assembly tolerances were fully redefined and dedicated tooling developed to meet the requirement dictated by the installation. The restart of the fabrication was accompanied by a close follow-up of the quality from Air Liquide and CERN inspectors at each production site. In order not to interfere with the new production, CERN decided to repair all the faulty elements by suppressing part of the non-conforming welds and replacing the internal sliding supports. To minimize the delay, the production sites were sized for at least twice the production. Remarkable was the production of the standard pipe elements which increased by a factor 2.3 (from 12 units/week to 30 units/week) in about 6 months' period: the production flow was fully revised to meet the new weekly rate and to balance the production time on the different assembly benches. Another advantage was the use of prefabricated blankets supplied by Jehier, France for the multilayer insulation at 80 K to replace the layer-by-layer wrapping performed by dedicated machines. The overall production of the service modules increased from 2.5 to 5 units/week mainly due to the addition of assembly tooling and a redistribution of the fabrication between Simic, FCM and Air Liquide DTA.

INSTALLATION

The installation of a QRL sector comprises the installation of about 700 external supports, the positioning of about 325 elements, and the welding of about 325 interconnections corresponding to about 2000 internal welds and 700 external welds. The overall QRL installation is carried out by 6 teams spread over two or three sectors. Three main types of inner header interconnections can be defined according to the number and types of welds. Except for the welds allowing for the final adjustment of each half-cell (about 53 m), all other internal welds are butt-welds. One of the specificities of a tunnel is its limited available space. Air Liquide developed a specific automatic orbital welding machine using open-head technology and capable of welding within a radial 60-mm space. In order to sustain the high productivity level, the machine included advanced features, such as camera control, automatic voltage control (AVC) and integrated wire reel. The inner headers are welded with orbital welding machines, whereas the external sleeves are manually welded. In order to achieve the requirements of the class B according to the EN 25617, each weld has to undergo several controls, such as external visual inspection (100 %), internal camera inspection (whenever possible), radiographic controls (from 100 % to 10 % according to the quality of welds) and helium leak test (100 %). Each sub sector is then leak tested individually before the final combined leak and pressure test of the entire sector. The technical objectives of the QRL installation have been reached, such as 20 standard interconnections a week and helium leak tightness test of each sub sector (about 400 m) in less than 3 weeks. After the installation of the first sector, the quality assurance plan was largely improved and for all phases of the installation specific procedures have been written by Air Liquide in collaboration with CERN. The installation activities were daily followed by Air Liquide supervisors and CERN inspectors. The percentage of welding defects reduced from 5 % for the first sectors to about 2 % for the last sectors (Air Liquide target value was 3 %). During the leak tightness test of the sub sectors, about 40 external leaks (over 4250) and 8 internal leaks (over 12000) have been detected. Leak detection procedure based on time-of-flight method has been developed to localize internal leaks over 428 m long sub-sectors in less than two weeks' time.

PROJECT STATUS

Figure 3 shows the progress of the fabrication of pipe elements and service modules, as well as the evolution of the installation and interconnection of the QRL elements. The fabrication started in the second quarter of the year 2003, was interrupted in the summer 2004, resumed at the end of the year 2004 and is now completed (1714 pipe elements and 310 service modules). The contractual period for the installation extended from July 2003 until November 2005. The installation started in July 2003 and was interrupted in May 2004 after the installation of the first sector whose elements were then cut, repaired and re-installed by CERN. The installation of the other 7 sectors remained with Air Liquide and re-started at the end of 2004. At present more than 7 sectors are already installed (including the first one by CERN) and the installation is expected to be finished by the end of 2006. Six sectors underwent successfully the pressure tests and the first two sectors have been successfully tested at cryogenic temperature [3], thus validating the QRL thermo-mechanical design.

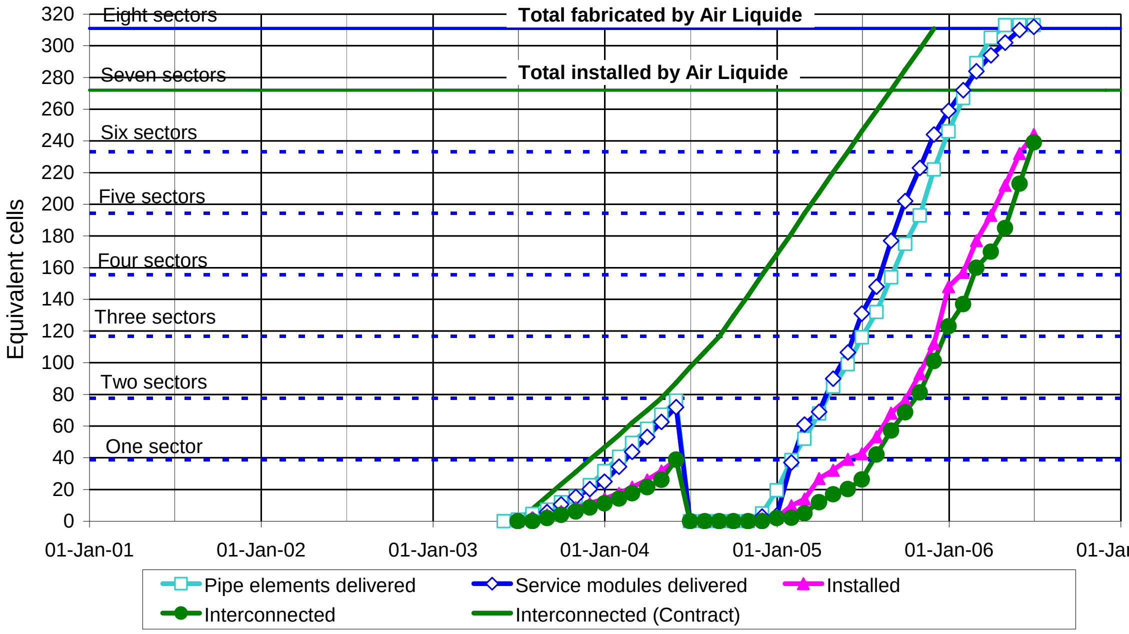

Figure 3 QRL fabrication and installation progress

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