QRL INSTALLATION AND FIRST EXPERIENCES OF OPERATION

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Abstract

The cryogenic distribution line (QRL) is divided in eight sectors, each of them about 3.2-km long. The installation of the sector 7-8 started in summer 2003, but due to serious technical problems the installed elements were cut, repaired and re-installed by CERN. The installation of the other 7 sectors was left to QRL Contractor and started with the sector 8-1 at the end of 2004. This paper gives the status of the QRL installation and the main results from the reception tests performed at cryogenic condition on the first two sectors (a portion of the sectors 7-8 and the full 8-1). The measured heat inleaks for different QRL configurations are also given and compared to the specified values.

INTRODUCTION

The cryogenic distribution line (QRL) [1] is divided in eight sectors, and each of them is a continuous cryostat starting at the cryogenic interconnection box located in the underground caverns, and ending at the return module installed on the opposite side.

Each sector is sectorised in 9 vacuum sub sectors (named from A to I), to easy installation and commissioning, and is composed of about 235 pipe elements, 40 fixed point (or vacuum barrier) elements, 10 steps and elbows mainly located in the so-called junction region connecting the interconnection box to the QRL in the tunnel, 2 cryogenic extensions and 40 service modules feeding the cryomagnets with helium at different temperature levels via so-called jumper connections. Each standard QRL cell (about 107 m) comprises 1 service module, 1 fixed point element and 8 standard pipe elements. The QRL insulation vacuum is divided from the machine insulation vacuum by means of vacuum barrier housed inside each jumper connection. A typical QRL cross section, showing the five process headers is given in Figure 1.

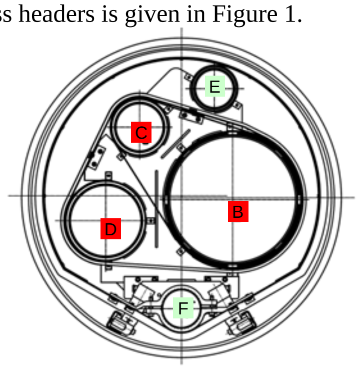

Figure 1: QRL cross-section

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. Three main types of inner header interconnections can be defined as illustrated in Figure 2:

- the "O" type for which one butt-weld per header has to be realised;
- the "C" type for which two butt-welds per header have to be realised. These interconnections contain the internal compensators;
- the "A" type for which three welds per header have to be realised. These interconnections are those allowing for the final adjustment of each half-cell (about 53.5 m).

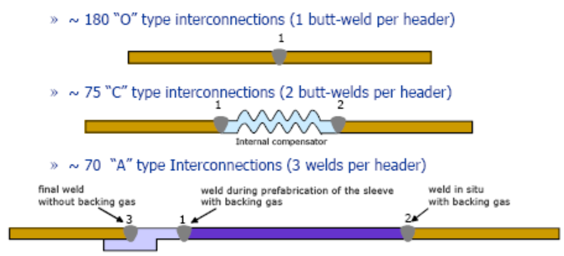

Figure 2: Main types of interconnections

The overall QRL installation is carried out by 6 teams spread over two or three sectors. The installation is carried out by sub-sectors. The inner headers are welded with orbital welding machines, whereas the external sleeves are manually welded.

The technical objectives of the QRL installation have now been reached, such as 20 standard interconnections a week and helium leak tighness test of each sub sector (about 400 m) in less than 3 weeks.

For the internal welds the following NDT tests are performed:

- internal (by using a video camera) and external visual controls at 100 %;
- radiography tests from 100 % to 10 % as a function of the weld quality;
- leak tightness tests at 100 % by using dedicated clamp shell tooling.

Each sub sector is then leak tightness tested individually before the final combined leak and pressure test of the entire sector.

PRESENT STATUS OF THE QRL INSTALLATION AND QRL SCHEDULE

At present the re-installation of the sector 7-8 by CERN is complete, as well as the installation by the QRL contractor of the sectors 8-1, 4-5 and 3-4. The installation of the sector 5-6 is advanced at about 75 % and that of the sector 6-7 at about 30 %. The installation of the sector 2-3 shall start mid on March 2006 and that of the sector 1-2 mid of June 2006. Figure 3 shows, for each sector, the schedule for the delivery of the main elements (service module, pipe elements and fixed points elements, and steps/elbows), as well as the time period for the installation, the tests and the consolidations after tests.

At present the production of the standard QRL elements is not critical for the installation schedule. As the service modules, pipe elements and fixed points elements will be delivered with sufficient margin not to delay the QRL installation. On the contrary, the production of the steps and elbows shall be followed very closely not to delay the installation of the last two junction regions.

Based on the present installation rate, it is possible to install one sector in about 20 weeks. This means that the installation of the last sector can be completed by the end of 2006.

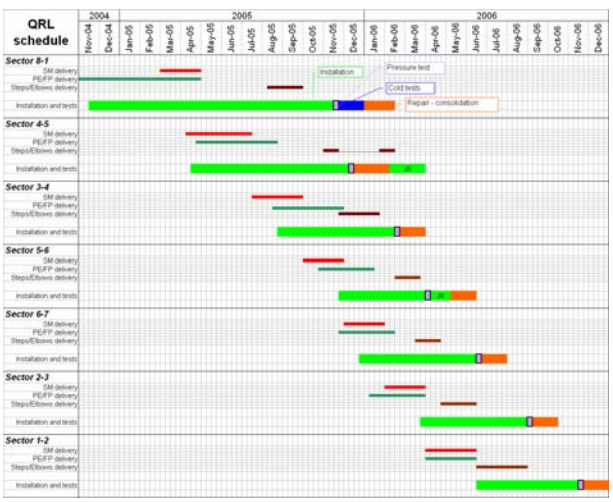

Figure 3: QRL schedule

RECEPTION TEST

Reception test schedule

The first two sub-sectors of the sector 7-8 (sub-sectors A and B, about 735 m) [2] and the full sector 8-1 [3] have been tested both at room temperature and at cryogenic conditions. They underwent to pneumatic tests, flushing with helium at high rate, cooldown to nominal temperatures, heat inleak measurements and warmup. The following two sectors (sectors 4-5 and 3-4) passed successfully the pressure test. The overall schedule for the reception tests of the sectors 7-8 and 8-1 is given in Figure 4. The pressure test is always performed during a week end and it is followed by the flushing with helium at high flow rate which has the aim of cleaning the circuits before cooldown. The cooldown of the sector 7-8 lasted about 3 days, whereas that for the sector 8-1 lasted one week. Once nominal cold conditions were reached the instrumentation could be validated (about 1.5 weeks), as well as the tuning of the refrigerator for the heat inleak measurements. The heat inleak measurements lasted about 2 weeks as different configurations had been tested (with and without active cooling in the jumper connections). The last phase of the reception test was the warm up which lasted few days.

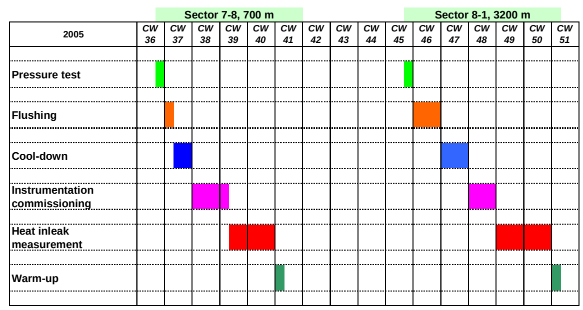

Figure 4: Schedule for the reception tests

Pressure test

The pressure test of the process headers is carried out at 1.25 their design pressure. For header B the design pressure is 4 bar, for headers C and D it is 20 bar and for headers E and F it is 22 bar. The test is declared as successful if the pressure is maintained inside the headers for at least one hour without significant variation, and if no relevant changes of the insulation vacuum are observed. The pressurisation is performed with helium at room temperature (see Figure 5). Up to about 20 bar the helium storage tanks and the warm compressors are used. From 20 bar to 27.5 bar, helium trailers and helium batteries are used.

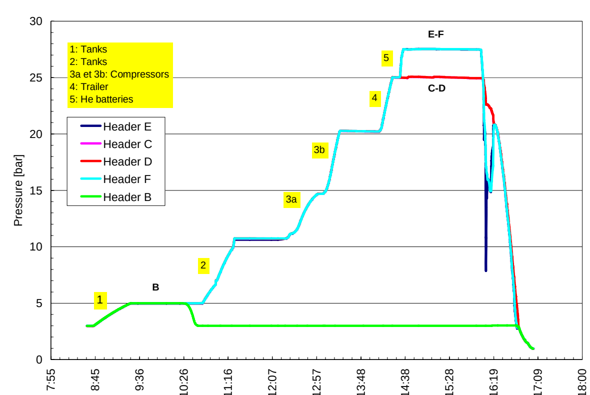

Figure 5: Pressure test of a typical QRL sector

Flushing of the circuits

Before starting the cooldown it is necessary to clean the circuits by circulation of room temperature helium at high mass flow rate. The circuits are cleaned one by one and the helium is returned to the refrigerator via header D. In the interconnection box a filter mounted on header D collects all the impurities coming from the headers. After the flushing of the circuits of the sectors 7-8 and 8-1, the header D filter was extracted and dust and metallic particles were found around the filtering surface.

Cool-down, thermometer validation and heat inleak measurement

The different phases (cool-down, instrumentation commissioning, heat inleak measurements and warm-up) of the tests at cryogenic temperature (named cold tests) for the sector 8-1 are illustrated in Figure 6.

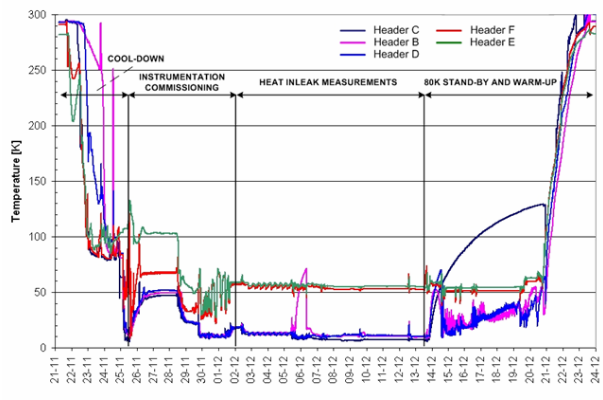

Figure 6: Cold tests of the sector 8-1

The schematic layout used for the QRL cold tests is shown in Figure 7. For the cold tests dedicated modules were required, such as the test module and the two test equipments. The test module was located in the tunnel between the junction region and the first service module and it housed all the required instrumentation to perform the heat inleak measurements. In absence of the cryomagnets, the two test equipments allowed for the helium in header E to return to the low pressure line of the refrigerator. During the test, each jumper connection was equipped with test boxes where short cuts between the different pipes could guarantee the continuity of the helium circuits. Two main circuits could be identified:

- the circuit at 4-20 K composed of header C (inlet header) and headers B and D (return headers)
- the circuit at 50-75 K composed of header E and F (both inlet headers for the cold test)

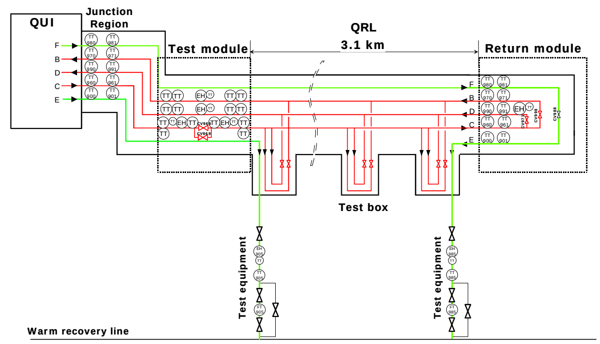

Figure 7: Schematic layout of the QRL cold tests

Before performing the heat inleak measurements, the thermometers have been validated at cryogenic temperature. Figure 8 shows the temperature distribution over the whole sector length. The result is very positive, as the measured temperature accuracy (considering the mounting of the sensor as well as the complete measuring chain) is about ±50 mK to be compared to the specified value of ± 1 K at about 10 K.

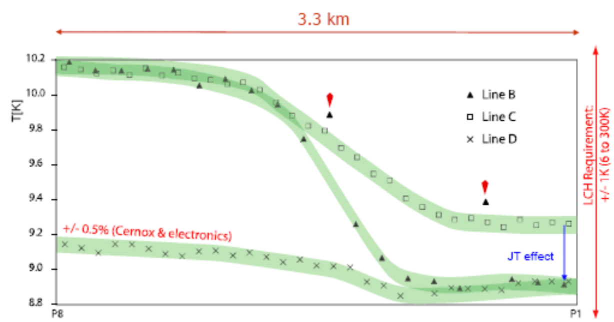

Figure 8: Longitudinal temperature distribution of the sector 8-1

The heat inleaks have been measured by enthalpy balance method knowing for each header the corresponding inlet-to-outlet temperatures (located in the junction region or in the service modules depending on the tested configurations) and the mass flow rate. The measured heat inleaks have been also cross-checked by using independent refrigerator input. The mass-flow rate in headers E and F have been obtained by using the mass-flowmeters installed in the test equipments. For the sector 7-8 (735 m) and 8-1 (3200 m), the measured and calculated (specified without any contingency) heat inleaks to headers E and F are given in Table 1. We can notice that the measured heat inleaks are lower than the calculated values.

Table 1: Heat inleaks to headers E and F

	Heat inleaks [W]	
	Sector 7-8	**Sector 8-1**
Calculated	2400	9850
Measured	2250 ± 150	9000 ± 400

The mass-flow rates in headers B, C and D were calculated by using the heaters in the test module, and cross checked by knowing the opening and the flow characteristics of the concerned valves. For the heat inleaks to headers B, C and D different configuration have been measured:

- QRL without the junction region (JR) and without the jumper connection (JC)
- QRL without the JR and with the JC
- full QRL with the JR and the JC.

The measured and calculated heat inleaks to headers B, C and D in the sector 7-8 are given in Figure 9, where the contribution of the JR and JC are added separately.

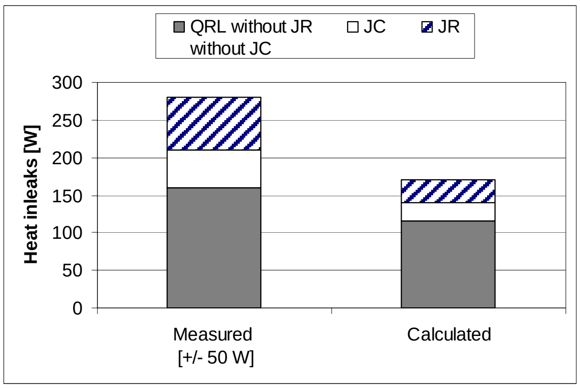

Figure 9: Heat inleaks to headers B, C and D in the sector 7-8

The same analysis has been made for the sectors 8-1 and is illustrated in Figure 10.

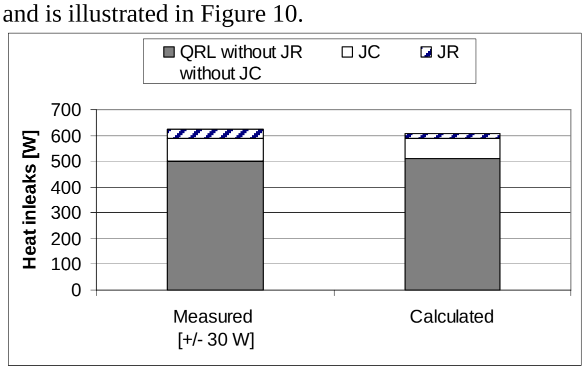

Figure 10: Heat inleaks to headers B, C and D in the sector 8-1

Table 2 gives the heat inleaks for each header and compares the measured to the calculated values.

Table 2: Heat inleaks to headers B, C and D in sector 8-1

	Heat inleaks [W]			
	B + C + D	**B**	**C**	**D**
Calculated	525	260	123	142
Measured [± 30 W]	535	270	108	157

From Figure 9, we can notice that the measured heat inleaks to headers B, C and D in the sector 7-8 are higher than the specified values. The difference becomes larger if the JC and JR contributions are considered. Possible causes for the higher heat inleaks might be the warmer thermal shield, the not nominal insulation vacuum in the jumper connection (>10^4 mbar), or few undesired thermal contacts between surfaces at different temperature levels.

The heat inleaks to headers B, C and D in the sector 8-1 are within the technical specification (see Figure 10) and this is also confirmed by considering separately the contribution of each header as shown in Table 2.

The comparison of the measured heat inleaks to headers B, C and D in sectors 7-8 and 8-1 is given in Table 3.

Table 3: Measured heat inleaks to headers B, C and D

	QRL without JC and JR	JC contribution	JR contribution
Sector 7-8	0.25 W/m	4.2 W/JC	1 W/m
Sector 8-1	0.16 W/m	2.4 W/JC	0.4 W/m

CONCLUSIONS

The installation of the QRL progresses well: the external supports are installed at 80 % and the elements at more than 55 %. Considering the current production and installation rates, it will be possible to terminate the installation of the last sector by end of 2006. At present the main concerns for the installation are the delay for leak detection and repair, and the installation of the QRL in the UJ22 and UJ24 underground caverns where all possible interferences with the cryo-magnet transport have to be avoided. The thermo-mechanical design has been successfully validated during the pressure tests of the sectors 7-8 (sub-sectors A and B only), 8-1, 4-5 and 3-4, and the tests at cryogenic temperature of the sectors 7-8 and 8-1. Flushing of the headers performed on the sectors 7-8 and 8-1 revealed to be indispensable and as a consequence for future tests sufficient time shall be allocated to this phase.

For the sector 8-1, the measured heat inleaks to the different temperature levels are within the specification. For the sector 7-8, the measured heat inleaks to headers E and F are within specification, whereas those to headers B, C and D are above. Possible caused have been identified to explain these higher measured heat inleaks. The thermometers have also been validated and the measured accuracy resulted to be much better than the specification.

ACKNOWLEDGMENTS

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