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RECEPTION TESTS OF THE CRYOGENIC DISTRIBUTION LINE FOR THE LARGE HADRON COLLIDER

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Abstract

The paper describes the thermo-mechanical validation of the first sector of cryogenic distribution line (QRL) [1]. The design of the line is recalled and the test methodology presented together with the main results of the reception test at cryogenic temperatures.

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The paper describes the thermo-mechanical validation of the first sector of cryogenic distribution line (QRL) [1]. The design of the line is recalled and the test methodology presented together with the main results of the reception test at cryogenic temperatures.

QRL DESIGN DESCRIPTION

The Large Hadron Collider (LHC) [2], presently under construction at CERN, will make an extensive use of superconducting magnets located in the underground tunnel of about 27-km length. The LHC ring is divided into eight sectors, each of about 3.3 km long. The superconducting magnets will be operated with superfluid helium at 1.9 K. To distribute the cryogenic helium to the local magnet cooling loops eight dedicated independent cryogenic distribution lines (QRL sector) will be used.

Each QRL sector (~ 3.3 km long) includes two supply and three recovery main pipelines, so-called headers. All headers are housed in a common external envelope. The QRL thermal insulation is guaranteed by the vacuum envelope, multilayer insulation wrapped on the screens at three temperature levels (75 K, 20 K and 4.5 K) as well as by using supports with low thermal conductivity.

The QRL sector starts at the cryogenic interconnection box, which directs helium from the LHC refrigerators to the QRL supply headers via a special elbowed junction region. Helium at different temperatures and pressures is distributed to the magnet local cooling loops every 107 m via the so-called jumper connections. The QRL sector ends with the return module, which ensures the helium flow continuity of the header circuits.

A QRL sector is composed of the junction region, 23 standard cells (each of about 107 m) and a number of special cells with variable lengths between 80 m and 96 m. The QRL standard cell consists of one service module, one fixed point element and eight standard pipe elements as shown in Figure 1. The service module with its equipment (control and on-off valves, sub-cooling heat exchanger, thermometers, pressure sensors, and jumper connection) is a direct cryogenic interface with the LHC machine elements and is used as a helium distribution device for the superconducting magnets. To cope with thermal contraction during operation and in case of accidental loss of insulation vacuum, a dedicated compensation system is installed between two fixed points, located respectively in the service modules and in the fixed point elements.

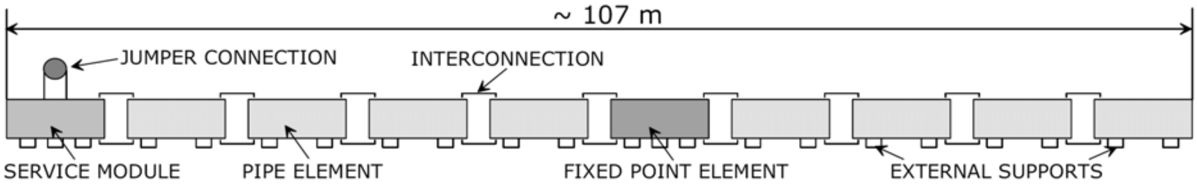

Figure 1 Scheme of the QRL standard cell

QRL TEST DESCRIPTION

The first QRL sector underwent reception tests at cryogenic temperature just after its installation in the tunnel [3] and before connecting with the LHC magnets. All jumper connections were closed with test boxes to form two main helium flow circuits. Headers C, B and D constituted the circuit at 4.5-20 K, whilst headers E and F together with the warm recovery line formed the circuit at 50-75 K (see Figure 2). A special test module, which was installed in the tunnel at the end of junction region, included all the instrumentation needed for indirect mass flow rate measurement in headers C, B and D (electrical heaters and upstream and downstream thermometers). In absence of the magnets a dedicated test set-up installed close to the return module connected header E to the warm recovery line and permitted direct measurement of the mass flow rate in headers F and E.

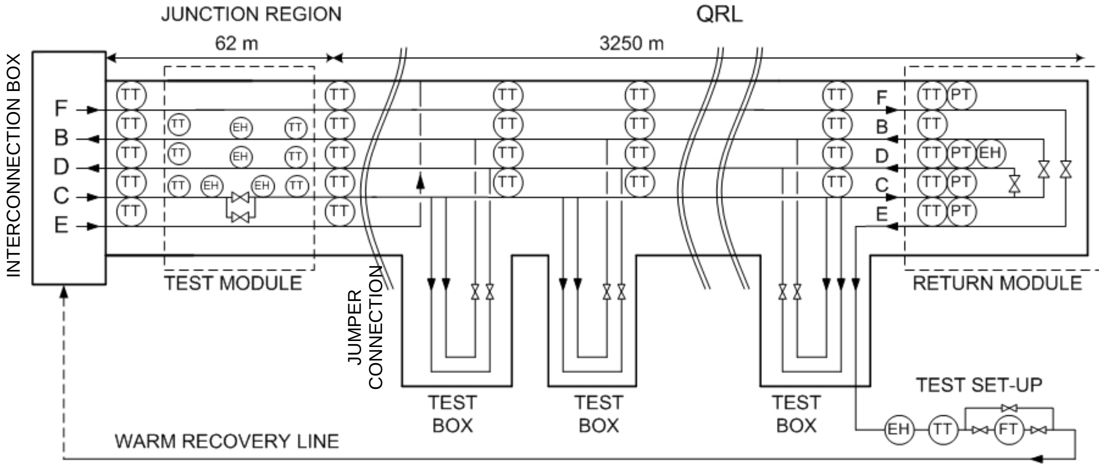

Figure 2 Schematic flow-scheme and layout for the QRL reception test

The reception tests were composed of four main phases: combined pressure and leak test at room temperature, cool-down to nominal temperatures together with instrumentation commissioning, heat inleak measurements, and warm-up to ambient temperature. The heat inleak measurements have been performed with and without active cooling of the jumper connections (i.e. with and without helium flow through all test box circuits).

HEAT INLEAK MEASUREMENT METHOD

To determine the heat inleaks, each main circuit was considered as a separate system with a specified number of inlets and outlets, and the energy balance equation for an open system with internal heat sources was applied

$$\dot{Q} = \sum \dot{m}_{out}\ h_{out} - \sum \dot{m}_{in}\ h_{in} - \dot{Q}_{EH}\ , \tag{1}$$

where $\dot{Q}$ is the calculated heat inleak, $\dot{m}_{in}$ and $\dot{m}_{out}$ are respectively the inflow and outflow mass flow rates, h_{in} and h_{out} are the helium specific enthalpies at inlet and outlet cross sections, and $\dot{Q}_{EH}$ is the heat flux generated by the electrical heaters EH (see Figure 2).

TEST RESULTS

The QRL reception test began with the pressure test during which each header was pressurized to 125% of its design pressure: header B to 5 bar, headers C and D to 25 bar, headers E and F to 27.5 bar. The test pressures were maintained for at least one hour without any significant change of the pressure inside the headers, thus validating the mechanical construction. During pressurization, for each sub-sector (4 standard cells, about 428 m) the helium signal was recorded and stayed below the specified value of 10^{-7} mbar·l/s. The pressure test was followed by cool-down from ambient temperature to about 80 K. During the whole period of the reception tests all signals from the instrumentation were continuously read and stored by a dedicated data-logging system. The corresponding temperature evolutions measured in the QRL at the interface with the interconnection box are presented in Figure 3.

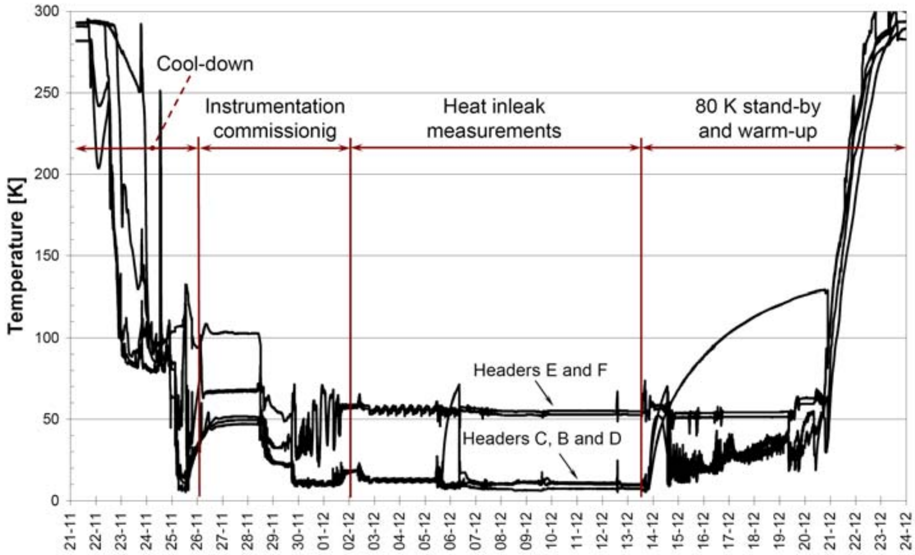

Figure 3 Temperature evolution for the QRL headers in the junction region

When the line reached 80 K and most of thermal contraction had occurred, the cool down was continued to the nominal temperatures: for headers E and F to about 50 K, for headers C, B and D to about 6 K. After complete cool-down the instrumentation was commissioned to check correct functionality of all thermometers, pressure transducers, heaters and valves. For the 280 thermometers the measured accuracy was about ± 50 mK, compared to the specified value of ± 1 K. The validation of the correct calibration and functioning of the instrumentation enabled the start of the heat inleak measurements. Because of considerable length of the line (3.3 km) and relatively low values of the expected heat inleaks to the circuit at 4.5-20 K, for each measurement a period of 12 hours was required to reach steady-state conditions. Several heat inleak measurements were performed with and without active cooling of the jumper connections. The insulation vacuum was equal to

$5 \cdot 10^{-4}$ mbar. The mass-flow rate in the circuit 50-75 K was in the range of 70-75 g/s and the helium inlet temperature and pressure were equal to 53 K and 11 bar respectively. In the circuit at 4.5-20 K the helium mass-flow rate was varied between 55 and 110 g/s, with the inlet temperature from 6.4 to 7.4 K and pressure from 1.9 to 2.4 bar. To reduce the influence of small unavoidable thermal and flow fluctuations on the measurement results, the registered data were analyzed statistically. The measured heat inleak values for both circuits are presented in Figures 4 and 5, and compared to the specified values. Figure 5 also gives the breakdown of the different contributions to the heat inleaks.

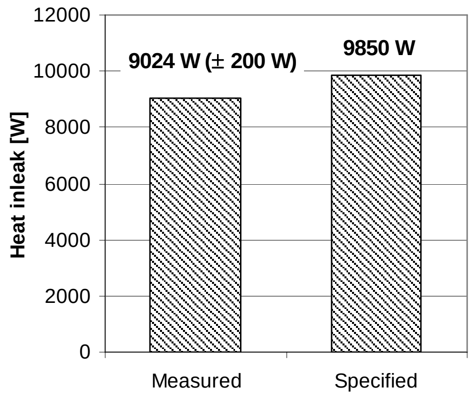

Figure 4 Summary of measured and specified heat inleaks for the circuit at 50-75 K

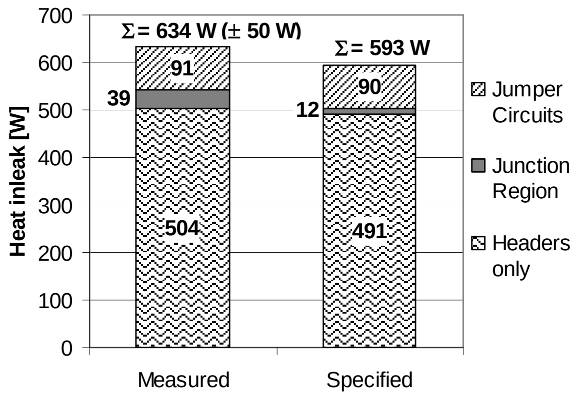

Figure 5 Summary of measured and specified heat inleaks for the circuit at 4.5-20 K

For the circuit at 50-75 K the measured heat inleaks are equal to 9024 W ± 200 W corresponding to about 3 W/m. The average value is 8 % lower than the specified value of 9850 W. For the circuit at 4.5-20 K the total measured heat inleaks were equal to 634 W ± 50 W corresponding to about 0.2 W/m. Giving the QRL contractor the benefit of measurement uncertainty, the measured heat inleaks were within the specification (593 W). The relatively high heat inleaks measured for the junction region (39 W) may result of specific, reinforced supports applied to the headers in this region. During the measurements, neither cold spots nor condensation were detected on the outside surface of the vacuum envelope. After the heat inleak measurements, the QRL sector was gradually warmed up to ambient temperature. The visual inspections of the sector, performed systematically during all test phases, confirmed the correct thermo-mechanical behavior of the line.

CONCLUSIONS

The thermo-mechanical performance of the QRL was successfully verified at cryogenic temperature. The applied methodology for the heat inleak measurement, based on the energy balance equation, allowed determining the heat inleaks with sufficient accuracy. The measured instrumentation accuracy was about 20 times better than specified (± 1K). The measured heat inleaks (3 W/m at 50-75 K and 0.2 W/m at 4.5-20 K) met the specified values.

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