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**A CRYOGENIC TEST SET-UP FOR THE QUALIFICATION OF
PRE-SERIES TEST CELLS FOR THE LHC CRYOGENIC DISTRIBUTION LINE**

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Abstract

Three pre-series Test Cells of the LHC Cryogenic Distribution Line (QRL) [1], manufactured by three European industrial companies, will be tested in the year 2000 to qualify the design chosen and verify the thermal and mechanical performances. A dedicated test stand (170 m x 13 m) has been built for extensive testing and performance assessment of the pre-series units in parallel. They will be fed with saturated liquid helium at 4.2 K supplied by a mobile helium dewar. In addition, LN₂ cooled helium will be used for cool-down and thermal shielding. For each of the three pre-series units, a set of end boxes has been designed and manufactured at CERN. This paper presents the layout of the cryogenic system for the pre-series units, the calorimetric methods as well as the results of the thermal calculation of the end box test.

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A Cryogenic Test Set-up for the Qualification of Pre-series Test Cells for the LHC Cryogenic Distribution Line

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Three pre-series Test Cells of the LHC Cryogenic Distribution Line (QRL) [1], manufactured by three European industrial companies, will be tested in the year 2000 to qualify the design chosen and verify the thermal and mechanical performances. A dedicated test stand (170 m x 13 m) has been built for extensive testing and performance assessment of the pre-series units in parallel. They will be fed with saturated liquid helium at 4.2 K supplied by a mobile helium dewar. In addition, LN₂ cooled helium will be used for cool-down and thermal shielding. For each of the three pre-series units, a set of end boxes has been designed and manufactured at CERN. This paper presents the layout of the cryogenic system for the pre-series units, the calorimetric methods as well as the results of the thermal calculation of the end box test.

1 INTRODUCTION

The LHC cryogenic system [2] is based on a five-point feed scheme with eight refrigeration plants serving the eight sectors of the LHC machine. Each of the eight sectors (~3.3 km) has its own self-standing cryogenic system. The cryogen is distributed at different temperatures and pressures via the Cryogenic Distribution Line (QRL) to the LHC magnet cryostats and other cryogenic consumers of the relevant sector. The QRL comprises supply and return headers including a sub-atmospheric one and is connected to the LHC cryomagnet every 106.9 m via the so-called Service Module. Following an in-house feasibility study, CERN adjudicated, in autumn 1998, three industrial contracts in parallel for the supply of Pre-Series Test Cells (~ 112 m) of the QRL, which will be tested at CERN in the current year 2000. The Test Cell comprises a LHC standard cell (106.928 m) and an additional Service Module needed for test purposes. The QRL Test Cell will first be used for validation of installation and quality control procedures. It will then be used to investigate the thermal and mechanical design by carrying out heat inleak measurements, mechanical and alignment tests and thermal cycling. To verify the chosen safety concept, loss of insulation vacuum will be tested as well. Finally, a visual inspection of the QRL Test Cell will be done. For each of the three Test Cells, a set of four end boxes has been designed and manufactured at CERN. Prior to their connection to the Test Cell, the end boxes will be fully tested and their heat inleaks will be measured.

2 TEST INFRASTRUCTURE AND LAYOUT

A test stand of 170 m x 13 m (see Figure 1) has been built to unload, install and test the QRL elements. In order to simulate the LHC curvature, the Test Cell will have the same polygonal shape as the line later in the tunnel. The concrete floor, 20 cm thick, has been sized to withstand the maximum load of 17 tonnes, which will be reached during the pressure test. The cryogen foreseen to cool the Test Cell is saturated helium at 4.2 K and gaseous helium at 80 K (see Figure 2). A 10 m³ helium dewar will be used to fill a

helium supply cryostat, from which the helium will be distributed to the three Test Cells. A 50 m³ nitrogen tank will feed a subcooler, which will cool-down the warm helium coming from the compressor station. Helium at 80 K will be needed for the cool-down and for cooling the thermal shield in nominal operation. Helium leaving the Test Cell will flow into the recovery line and recirculate via a close loop into the warm compressor station. To perform the reception tests as close as possible to the LHC operating conditions, four end boxes will be mounted to each extremity of the Test Cell. The supply and return boxes, situated on each extremity, will supply with helium the main cooling circuits and interconnect the main headers. Two test boxes will be used to simulate the interfaces to the LHC cryomagnets and to close the circuits feeding the LHC cooling loops. The heat inleaks of the end boxes will be measured separately in a dedicated test set-up. For this purpose, the end boxes will be connected together via the “link module”, which, replacing the Test Cell, will guarantee the continuity of the inner circuits. The end boxes house the phase separators allowing for measuring the heat inleaks, as well as the control valves needed for the Test Cell operation.

3 OPERATION MODES AND HEAT INLEAK CALCULATION

The Test Cell (see Figure 1a) comprises a thermal shield cooled by header F at about 70 K and three headers at 4-20 K, namely headers B, C and D. The temperature levels for the Test Cell are the same as those envisaged for the LHC machine: header C will be used as a supply line and headers B, D and F as return lines. The main difference concerns the header pressures, which for the Test Cell will be around 0.1 MPa for all of them. The cryogenic system will allow for testing two Test Cells in parallel under different operating condition. The hydraulic circuit of the test cell is shown in Figure 2. The one for the Dummy Test can be obtained by replacing the Test Cell with the link module. The main operation modes are cool-down, nominal operation, warm-up and thermal cycling. The end boxes will operate in the same pressure and temperature condition as later the Test Cell. For the dummy test, helium at 4.2 K will be used both for cool-down and nominal condition. For the Test Cell, cool-down from 300 K to 80 K will be performed by using gaseous helium at 80 K tapped from the nitrogen subcooler. During nominal operation, saturated liquid helium, tapped off from header C, will fill the phase separators in the Test Boxes via the interconnection pipes of the corresponding Service Modules. The other interconnection pipes tapped from header C will be filled by gravity with liquid helium from the phase separator. The vapour, produced in the phase separators of the Test Boxes A and I, will return to headers B and D. The phase separator in the return module will allow to collect the remain gas produced in header C. During nominal operation, the valves in the return box connecting C to B and D (V19 and V20) will be kept closed. The gaseous helium at the outlet of headers B and D will be mixed to helium at 80 K from the N₂ subcooler and then heated up to a temperature of about 65 K to cool the screen circuits. Warm-up from 4.2 K to 300 K will be performed by circulating warm helium inside the main circuits.

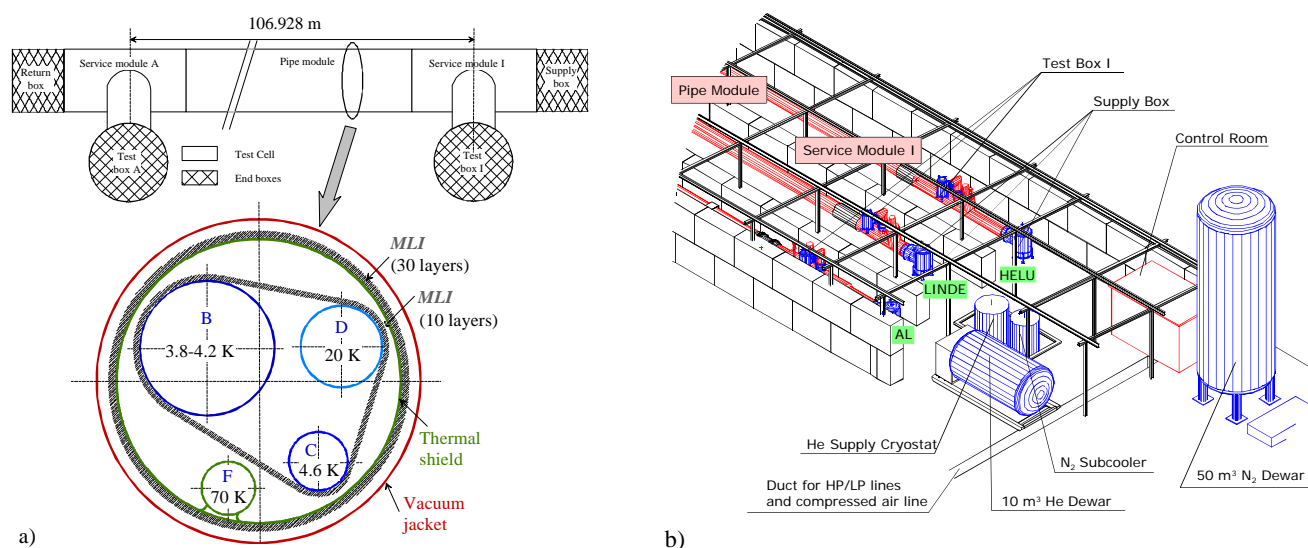


Figure 1 Simplified layout of the Test Cell (a) and its test infrastructure (b)

The heat inleaks on headers C will be calculated by helium boil-off. In steady state condition the heat losses can be compensated and the level in the phase separators kept constant by controlling the valves filling the phase separators (V2, V6 and V10). From the first principle of thermodynamics, it follows:

$$Q_C = \dot{m}_v \cdot [H_{2\text{liq}} - H_{1\text{gas}}]$$

where \dot{m}_v is the vapour mass flow-rate, $H_{2\text{liq}}$ and $H_{1\text{gas}}$ are the enthalpy of saturated liquid and gas respectively before and after the level control valves V2, V6 and V10 (see Figure 2).

The heat inleaks on headers B, D and F will be evaluated by enthalpy difference knowing the mass flow-rate and inlet-to-outlet temperature differences as follows:

$$Q_{B,D,F} = \dot{m} \cdot (H(T_2) - H(T_1))$$

where \dot{m} is mass flow-rate and $H(T)$ the enthalpy of the flow at the outlet and inlet temperatures, respectively T_2 and T_1 . For headers B and D, the mass flow-rate measurement is not direct and it can be obtained by imposing a known heat input and measuring the corresponding upstream (T_1) and downstream (T_2) temperatures:

$$\dot{m} = \frac{Q_{\text{el}}}{(H(T_2) - H(T_1))}$$

The heat inleaks into the End Boxes were calculated taking into account the dimensions of their thermal shields, inner components (such as phase separators), transfer lines, valves, and type of instrumentation. Heat transfer by conduction, radiation, and through MLI were considered. In this last case, the heat flux from 300 K to 80 K was considered equal to 1.2 W/m^2 and from 80 K to 4.2 K to 0.6 W/m^2 . In the region of critical components (such as valves), heat fluxes through MLI were multiplied by a factor of 1.5. Table 1 summarises the heat inleaks calculated for the End Boxes. The heat inleaks on lines C and F are mainly due to valves and transfer lines. The values presented in Table 1 allow an estimate of the temperatures and mass-flows, which can be measured during the heat inleaks test as a function of the overall heat losses into the End Boxes. Considering also the heat power needed to reach the specified temperatures, we expect to consume about 0.4 g/s of liquid helium under steady-state nominal operation.

4 INSTRUMENTATION AND DATA ACQUISITION

Each Test Cell comprises more than 160 sensors and actuators, distributed over 110 m on a Profibus DP/PA network [3]. The sensors include about 100 thermometers and several pressure, flow and level transmitters. The actuators consist of 20 heaters and 30 valves. Temperatures are measured with Allen-Bradley carbon sensors used from 4–30 K, Cernox™ (Lakeshore Cryotronics, Inc.) sensors employed from 4 to 300 K and PT100 platinum sensors from 30 K to ambient temperature. The temperature on the vacuum side is measured by industrial-type cryogenic thermometer with built-in heat interception [4]. The thermometers used to evaluate the heat inleaks are redundant. To improve the reliability and the time response of the thermometers used after the heaters EH1 and EH2 (see Figure 2), the sensors have been immersed directly in the helium.

Heat inleaks [W]	C	B	D	F
Supply box	0.004	0.10	0.10	25.24
Test box I	0.59	0.00	0.004	4.83
Return box	0.22	0.77	0.77	21.01
Test box A	0.59	0.39	0.01	6.13
Link Module	0.02	0.02	0.03	0.01
TOTAL	1.424	1.28	0.91	57.22

Table 1 Total heat inleak values calculated for the End Boxes

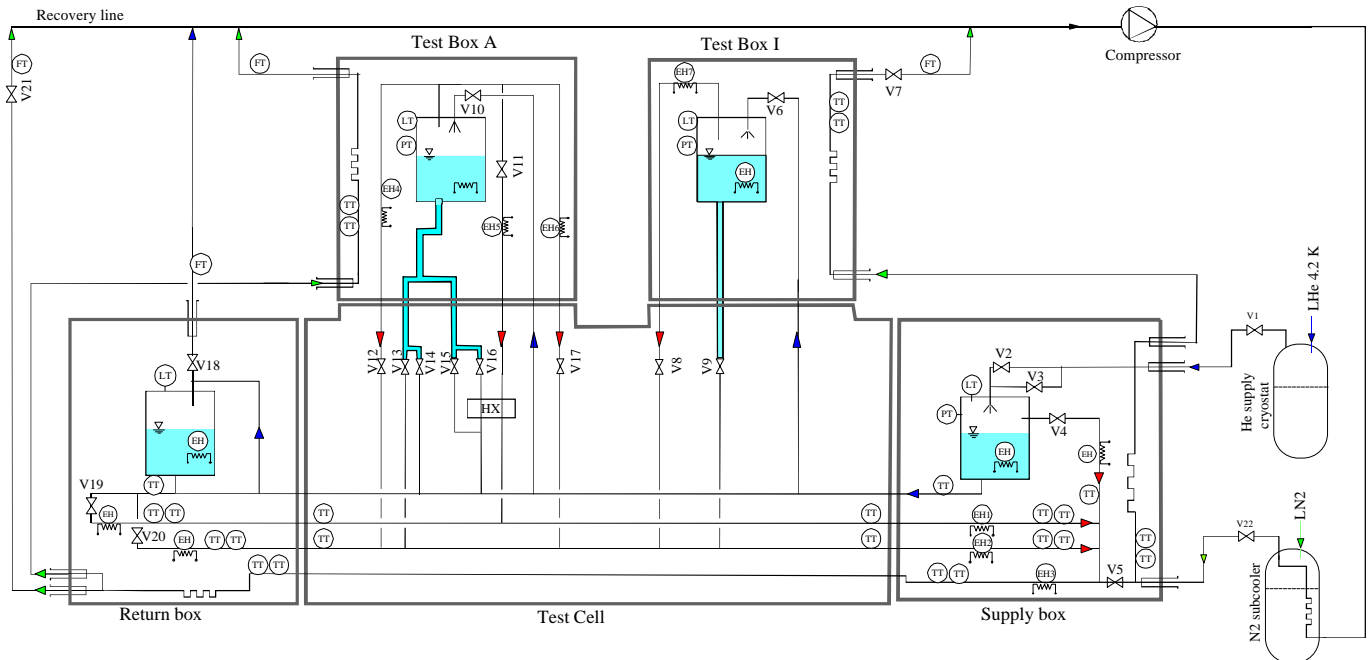


Figure 2 Hydraulic flow scheme of the test cell

Current sources are restricted to 1 μA for carbon sensors and 1 mA for the platinum sensors to minimise resistive heating. A Programmable Logic Controller (PLC) implements more than 30 closed control loops and takes care of alarms, interlocks and overall process control. Inlet and outlet temperatures of headers B, D and F are controlled by varying the corresponding power heaters (EH1 to EH7). The level in the phase separators is kept constant by regulating the flow of liquid helium through valves V2, V6 and V10. The data acquisition system is based on the PCVue™ (Arc Informatique) application. During all operational phases, data are saved on files as spreadsheets readable by most data analysis applications. From an overall estimate of instrumentation errors, we are able to record heat inleaks with a precision of $\pm 10\%$.

5 PROJECT STATUS

The first set of end boxes has been manufactured, assembled and evacuated by January 2000. The pressure test and parallel helium leak detection were performed successfully. The inner circuits have been cooled in 4 h by circulating 3.5 g/s of liquid helium at 4.2 K. The total helium inventory of the system is about 10 kg. The residual gas pressure in the cryostat is 10^{-4} Pa. Cold functional tests on instrumentation, process control and data acquisition are being performed. Heat inleaks on the different headers will then be measured and the results compared to the calculated values. Once the first set of end boxes is tested, it will be connected to the QRL Test Cell. The test program for the following 6 months foresees the heat inleak measurement of the other two sets of end boxes and the parallel qualification of the three QRL Test Cells. Only those firms having supplied a QRL Test Cell, which has successfully been tested at CERN, will be considered for the final tendering of the QRL sectors for the LHC.

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