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Abstract

ATLAS is a very high-energy detector for the Large Hadron Collider (LHC) at CERN. The superconducting magnet used to provide the required magnetic field consists of four sub-systems: a central solenoid and a very large toroidal magnet comprising two end-cap magnets and the barrel toroid magnet. The associated cryogenic system, currently in the final specification and procurement phase has been sub-divided into three parts: internal, proximity and external. The internal cryogenics minimizes and extracts the heat loads to/from the 4.5 K cold mass and its thermal shields, while the proximity cryogenics takes the cooling capacity generated by the external common system and distributes it to the four magnets according to the various operating scenarios. Two independent proximity cryogenic systems have been designed taking into account the difference in cooling principle of the solenoid and the three toroids, respectively.

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ABSTRACT

ATLAS is a very high-energy detector for the Large Hadron Collider (LHC) at CERN. The superconducting magnet used to provide the required magnetic field consists of four sub-systems: a central solenoid and a very large toroidal magnet comprising two end-cap magnets and the barrel toroid magnet. The associated cryogenic system, currently in the final specification and procurement phase has been sub-divided into three parts: internal, proximity and external. The internal cryogenics minimizes and extracts the heat loads to/from the 4.5 K cold mass and its thermal shields, while the proximity cryogenics takes the cooling capacity generated by the external common system and distributes it to the four magnets according to the various operating scenarios. Two independent proximity cryogenic systems have been designed taking into account the difference in cooling principle of the solenoid and the three toroids, respectively.

INTRODUCTION

In the framework of the LHC project at CERN, ATLAS [1] is one of the experiments under construction. The cryogenics related to it concerns both the use of liquid argon [2] for the calorimeter and liquid helium [3] for the magnets. The paper described here refers to the helium cryogenics, which distributes the liquid and cold gas helium to the Barrel Toroid (BT) and to the End Caps Toroids (ECT).

The project is the result of the collaboration between CERN, RAL and CEA. The conceptual design and the status of the project are summarized.

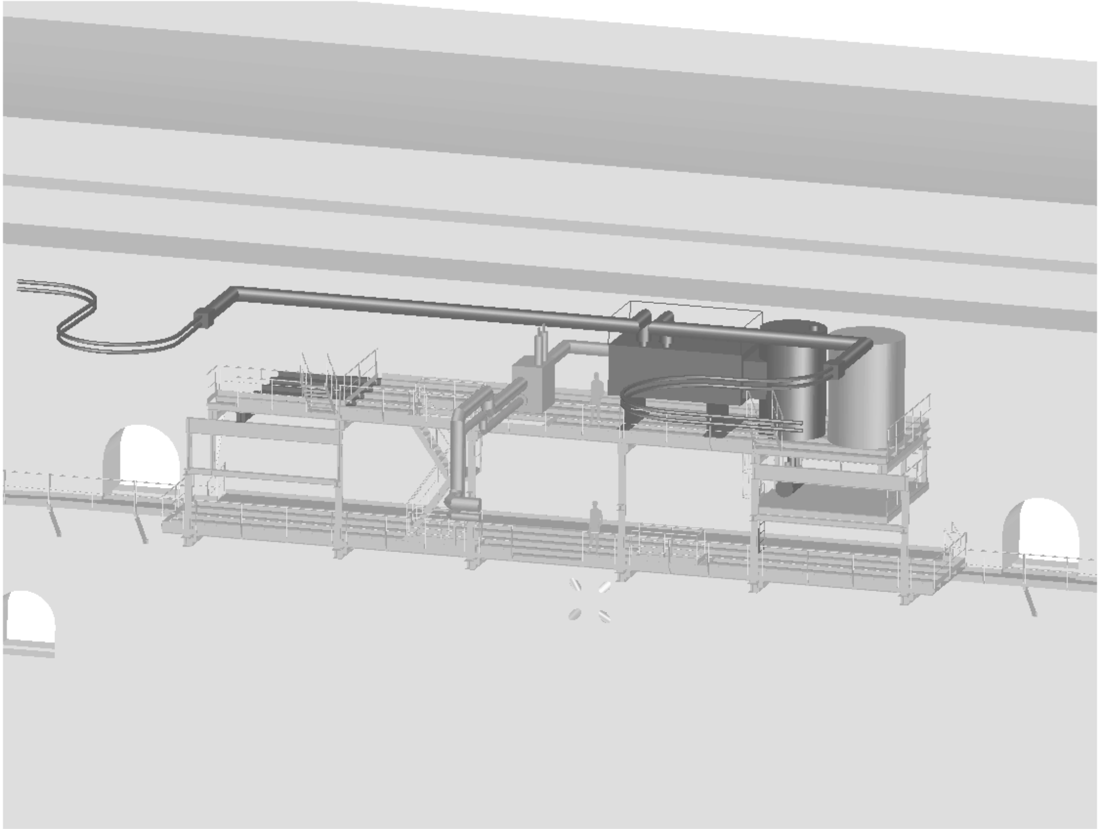

FIGURE 1. The Proximity Cryogenics System of ATLAS is shown. On the above platform the different components could be seen located at the height of 20 m from the floor of the experimental cavern. The floor is at about 90 m below the ground level.

GENERAL DESCRIPTION

The Proximity Cryogenics System (PCS) is composed of a distribution valve box, a phase separator, a buffer dewar, and a current lead cryostat for the BT and the different transfer lines which connect these components among themselves and to the magnets. A cryostat housing two helium centrifugal pumps (one for redundancy) is also part of the system. The pumps provide a forced flow of saturated liquid helium cooling indirectly the superconducting magnets of the BT and ECT. Each pump has a nominal mass flow 1200 g/s at the nominal head of 40 kPa (400 mbar). A general view of the PCS can be seen in FIG 1, where the different components are shown placed at the height of 20 m from the floor in the ATLAS cavern.

A schematic flow scheme is shown in FIG 2. Two different refrigerators provide the needed cooling capacities to the PCS: a helium shield refrigerator of 20 kW capacity at 40-80 K and a helium refrigerator of 6 kW capacity at 4.5 K entropy equivalent. The shield refrigerator is used both for the cooling of the thermal shields, and for the cool down from 300 K to about 100 K. The 6 kW refrigerator provides the cool down of the magnet from 100 K to 4.5 K and the cooling capacities for normal operating conditions. In normal operation the 6 kW refrigerator keeps a constant level of LHe at 4.5 K in the phase separator of PCS. The LHe is withdrawn to the suction of the centrifugal pump, which distributes it in parallel to each of the two ECT's and to the BT: in all magnets there are eight parallel circuits one for each race-track coil. The flow of each BT circuit is controlled

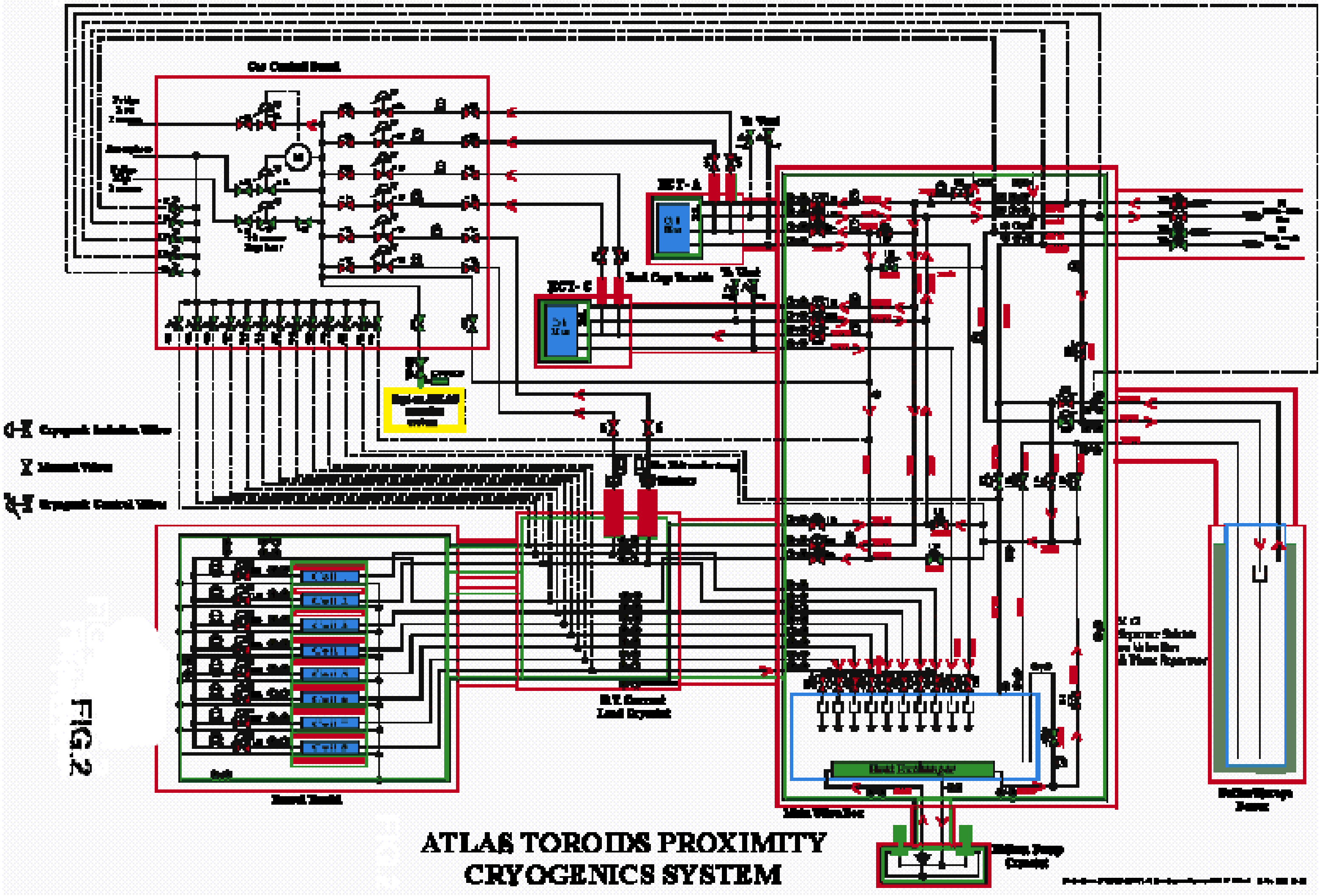

FIGURE 2. Flow scheme of the Proximity Cryogenic System

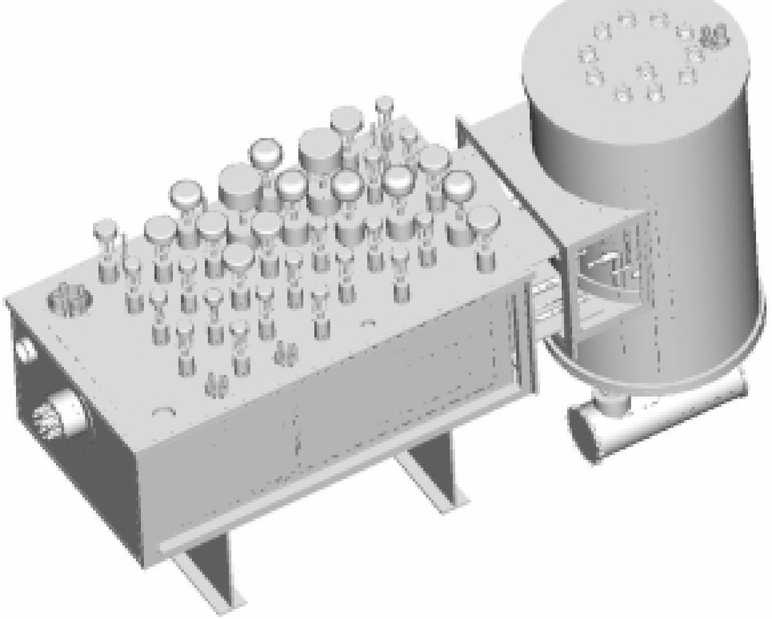

FIGURE 3. The main valve box (left) and the phase separator of PCS. At the bottom of the phase separator the helium pump cryostat can be seen.

by cryogenic valves and orifices whilst only calibrated orifices equalize the distribution of the liquid helium in each ECT's. Liquid helium is also used for cooling the three pairs of the 20 kA current leads. The liquid and vapor helium mixture from the ten outgoing lines (the two ECT's and the eight circuits of the BT) return to the phase separator, which is directly connected to the 6 kW refrigerator. A buffer dewar of 11000 liters capacity is also connected (right hand side of FIG 2) to the 6 kW refrigerator and the phase separator to provide, in case of refrigerator failure, the cooling capacity during slow dump of the energy (1.6 GJ) stored in the magnets.

DISTRIBUTION BOX AND PHASE SEPARATOR

The distribution valve box (DVB) is shown FIG 3. It shares the vacuum with the phase separator. Vacuum barriers are foreseen for the transfer lines towards the ECT's , the BT and the connection to the refrigerators. The rectangular shape has been chosen to comply with the available space and for an easy accessibility to the inside. The transfer lines to the BT are connected first to the current lead cryostat and from there to the distribution ring of the BT, via two lines housing separately the cryogenic pipes and the bus bars. The DVB is manufactured mainly in stainless steel: the two side parallel plates, which enable the access to the inner piping, are made out of aluminum alloy to minimize the overall weight.

The DVB includes some 33 cryogenic valves flanged on the top horizontal plate, and it is equipped with an active copper shield cooled by the shield refrigerator. The shields are made of copper plates with copper tubes soldered on them. Various sensors are located as indicated in FIG 2.

The phase separator, also equipped with an active shield, is welded to the DVB and it is made out of stainless steel and designed for 2 MPa (20 bar) maximum pressure. In the phase separator (capacity is ca. 4700 liters) a 1 kW electric heater is installed, which will be used for the compensation of the rapid heat load fluctuations during ramp up or ramp down of the field of magnet. A heat exchanger is located at the bottom of the phase separator, in order to extract most of the heat introduced by the centrifugal pump, which increases, when operated at the above indicated nominal conditions, the liquid helium temperature of ca. 0.1 K. The expected efficiency of the heat exchanger is 80 %.

THE PUMP CRYOSTAT

The pump cryostat is located below the phase separator. It houses two centrifugal pumps, which can be replaced by accessing the inside from two lateral flanges. The pumps are also designed in such a way that the motor, the shaft and the impeller can be extracted from the top and replaced, without removing the housing welded on the cryostat and on the liquid helium pipes.

The two pumps, for nominal operating conditions, will run at 3950 rpm with an expected efficiency of about 50% (hydraulic power/shaft power). Each pump is designed to have a heat load, due to the thermal conduction from 300 K to 4.5 K, below 20 W. Each pump is also equipped with a non-return check valve, to prevent the counter-rotation of one when the other is in operation. The check valves also protect the pump against possible overpressure coming from the magnet circuits. The running of each pump in a closed circuit on the phase separator is also foreseen, in order to measure their performances when in place. The first prototype of the pumps will be delivered late this year and it will be extensively tested [4] at CERN in a purpose built test facility, at the moment under construction.

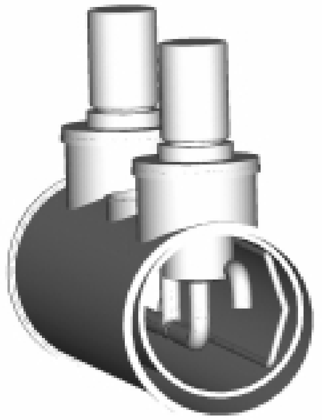

FIGURE 4. The Helium Pump Cryostat. Accessibility for the change of a pump is from the side flanges.

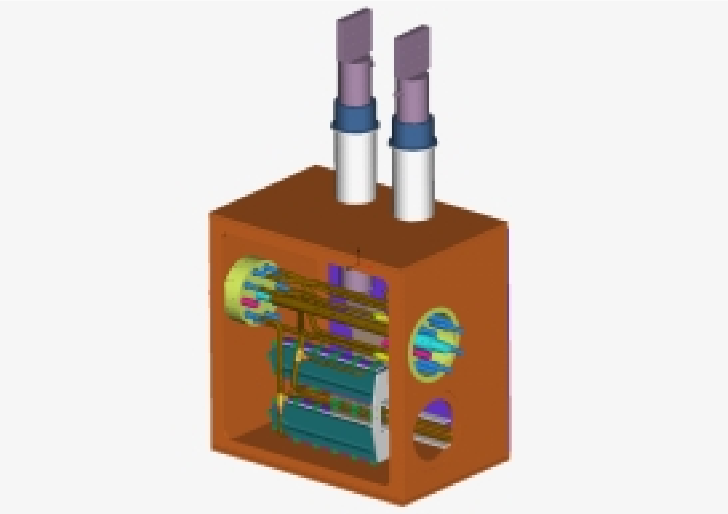

FIGURE 5. The Current Lead Cryostat for the BT. The vacuum barrier (on the left-hand side), from the distribution valve box, is visible.

THE CURRENT LEAD CRYOSTAT

Part of the liquid from the pumps is sent to the bottom part of the three pairs of conventional type current leads, each one capable of sustaining up to a maximum of 25 kA and a pressure above 2 MPa (20 bar). The current leads have been tested at CERN [5] up to the maximum current and it has been measured that, at 20 kA, i.e. the nominal current values, the consumption was ca. 1.5 g/s for each lead. The current lead cryostat for the BT is shown in FIG 5. It is constructed of stainless steel and it contains an active shield and a vacuum barrier on the multi-pipe transfer line towards the DVB. No vacuum barrier is foreseen for the more complex cryogenic transfer line to the BT interface, which contains the superconducting bus bars.

THE FLEXIBLE TRANSFER LINES

Due to the necessity to move, without interrupting the cooling, the two ECT's from their working position to the parking place, part of the cryogenic transfer lines from the DVB to the ECT's has to be flexible. The lines will be supported by special "drag chains" similar to the ones used for complicated routing of the cables. For that purpose two coaxial lines are foreseen for each ECT. One for the LHe and 40 K as shield and the other for liquid/vapor mixture and 80 K gas shield returns.

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