Barrel Toroid Cryogenic System for the ATLAS Detector

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The ATLAS barrel toroid is a superconducting magnet assembly of eight independent coils. Each coil comprises a cryostat, a 60 K helium gas shield and a two-phase 4,5 K cooling circuit. The helium supply of each one is regrouped in a common cryogenic ring which includes also the 20 kA bus. After a 30 days cool-down, the running mode is based on two 600 g/s cryogenic pumps. The first one delivers this nominal mass flow of subcooled liquid helium and the second one runs slowly in case of default on the running one. In order to avoid a fast dump of the magnet, the rapid commutation of the pumps is necessary. The paper describes the different cryogenic subsystems.

GENERAL

The central air toroid consists of 8 superconducting coils supported by a warm mechanical structure. It operates at an average temperature of 4.5 K. This temperature is obtained by a two-phase helium circulation. The vapor quality in the coils is controlled around 10 %. Helium is provided by cryogenic pumps, which deliver a 600 g/s mass flow rate, through a cryogenic ring.

This ring supplies helium to all the coils, all the shields at an average temperature of 60 K and contains the bus bar to power the magnet. This ring is connected to the coils in their central part. This ring is connected to a power cryostat which includes the 20 000 A current leads. This connection is located in the low and straight section between the ring and the main valve box. This part is called main cryogenic line.

The main valve box is located in the experimental cavern. It provides the magnet with the different fluids by a lot of valves and contains the two liquid helium pumps.

A 5000 litre dewar is connected to this box to supply the helium loop.

A two-phase separator is placed at the top of the magnet to recuperate the two-phase helium. This 800 litre dewar contains the control system of the mass flow in each coil and supports the safety valve.

The roughing and primary pumping-out of the coil vacuum chambers is provided by a 2000 m^3/h pumping set situated in the experimental cavern through the cryogenic ring. The secondary pumping is carried out by nine 3000 l/s diffusion pumps (one per coil and one on the main valve box) connected to the primary one.

The refrigerating system, composed of a nitrogen precooler and of a refrigerator, supplies helium at different temperatures during the different cryogenic phases of the magnet. The expansion is done in the valve box and produces liquid helium in the 5000 l. dewar.

All these items are shown in the figure 1.

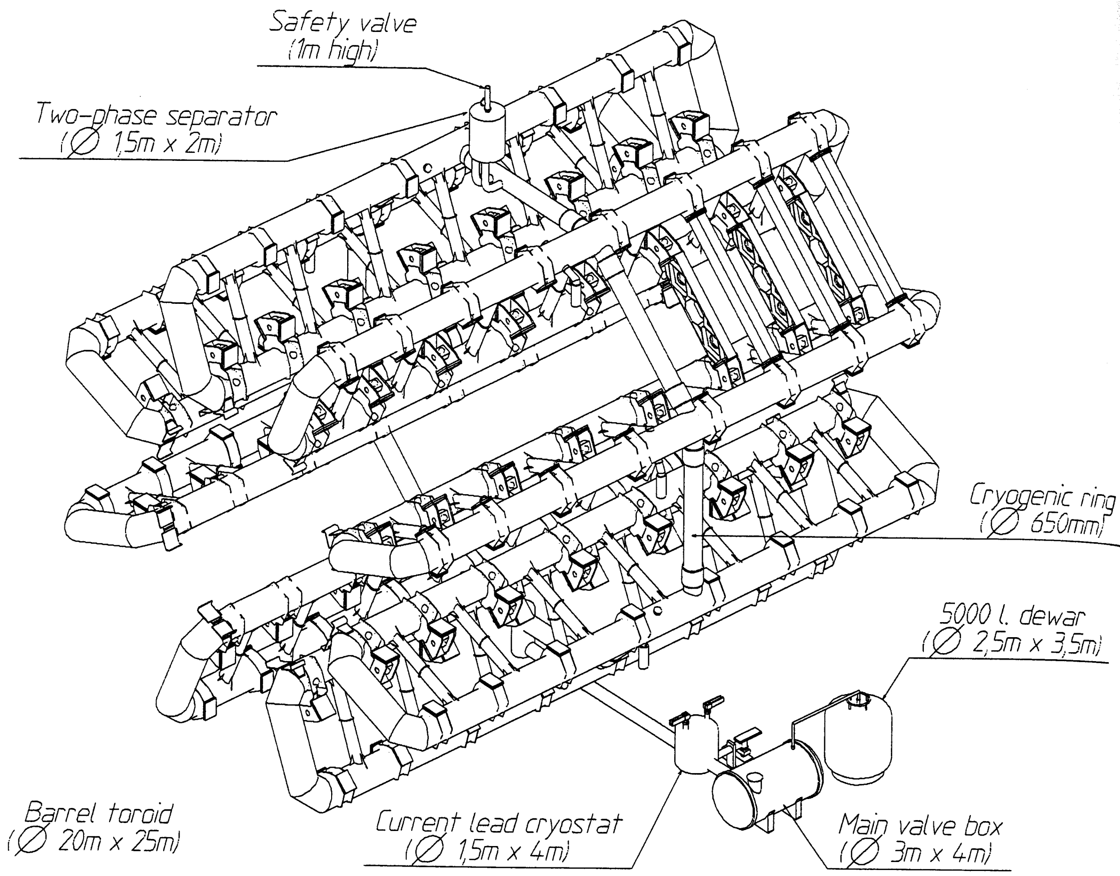

Figure 1

The cryogenic components are divided into three parts :

-the external cryogenics which includes all the components in relation with the refrigeration system and the cryogenic lines down to the main valve box. CERN is totally in charge of this part,
-the close cryogenics which includes the differents elements mentionned above located in the experimental cavern and the control process equipements,
-the internal cryogenics which concerns the coil equipements.

COOL-DOWN

Cool-down involves the gradual cooling of the heat shields from 300 to 60 K and of the coils from 300 to 4,5 K. It takes place in a general process of the magnet cool-down and must follow three criteria :
- a mechanical one which involves a maximum temperature difference between the coil inlets and outlets of 40 K,
- a thermal one which involves that the shields follow the coils in temperature,
- an experimental one which involves that the cool-down gradient do not exceed 0,5 K/hour above 100 K.

Cool-down is a gradual process, taking some 30 calendar days, into two stages :
- from 300 to 100 K for coils and shields with gaseous helium gradually cooled from 300 to 80 K by liquid nitrogen in a pre-cooler (~ 20 days).
- from 100 K to 5 K for coils directly by supercritical helium at 5 K from the refrigeration system (~ 10 days).

POWER REQUIREMENTS

4,5 K level	
Cold mass (kg)	350000
Cold mass area (m^2)	1800
Radiation and shields supports (W/m^2)	0.3
Conduction in cold mass supports (W)	70
Close cryogenics (W)	30
Pump heat load (W)	250
Conduction in the pumps (W)	40
Total (W)	930

Each coil is hang on eight rods which support each between 100 and 200 tons due to the magnetic forces. The weight of the coil in any direction is supported by 32 cryogenic thrust blocks along the coil box which are linked to the shields.
The stored energy of the barrel is 1130 MJ.

60 K level	
Shield mass (kg)	25000
Shield mass area (m^2)	1800
Radiation and shields supports (W/m^2)	3
Conduction in cold mass supports (W)	1580
Close cryogenics (W)	450
Total (W)	7430

Current leads	
Mass flow (g/s)	3
Power (W)	60

RUNNING MODE

The shields run at an average temperature of 60 K by 40 K cold gaseous helium from the refrigerator. The eight shields are connected in parallel from the supplying pipe in the cryogenic ring. The total mass flow is regulated by a valve located in the main valve box at the inlet of the circuit. The mass flow repartition between the shields is obtained by a calibrated pressure drop on each shield circuit.

The coils are kept at an average temperature of 4.5 K by a forced liquid helium flow circulation.The liquid helium circuit is made of two 600 g/s circulators connected in parallel as shown in figure 2. The circulator in use provides the nominal mass flow rate and the second one is on stand-by only kept cold at a low rate of operation. An analysis system controls the running pump behaviour and switches on the other in few seconds in case of default.

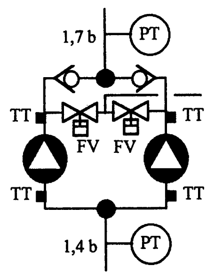

Figure 2

The flow rate in each coil is monitored by a regulating valve located in the main valve box at the inlet of the circuit. Each one is controlled by a pair of flowmeters. The first, after the regulating valve, is a diaphragm system which measures the total mass flow and the second, in the two-phase separator at the end of the circuit, is a sink-type system which measures the liquid part of the two-phase helium. This measurement cross-check gives the vapor quality and allows to adjust the mass flow rate in each coil.

The fluid liquid part falling in the separator returns to the inlet of pumps through the cryogenic ring. The fluid gaseous part returns to the refrigerator by the same way. The 5000 litre dewar provides the loop with liquid helium in order to compensate the losses. This contribution is monitored by a regulating valve which is controlled by the total level in the separator. The filling up of this dewar is ensured by the refrigerator and its level is regulated by the JT valve. This tank must be pressurized and this pressure is controlled by the returned gaseous helium regulating valve. Its size allows a slow dump in case of refrigerator failure.

The cooling circuit of the current leads is connected to the returned liquid helium pipe at the bottom of their cryostat. The superconducting bus bar going through the cryogenic ring is also cooled by this pipe.The mass flow on each current lead is controlled by a gas flowmeter at the warm outlet tube after the flag.

INSTRUMENTS

The overall control of this magnet (cool-down, running mode, discharge) needs a large number of sensors and valves. In order to avoid many cables in the cavern, we propose to use a field bus to relay the measurements. Boxes on each coil, the main valve box, the current lead cryostat and the two-phase separator convert analogic signal into numerical data. Then these data are treated by a dedicated programmable automatic system as shown in figure 3. The pump commutation is specially ensured by a software process which increase the system availability.

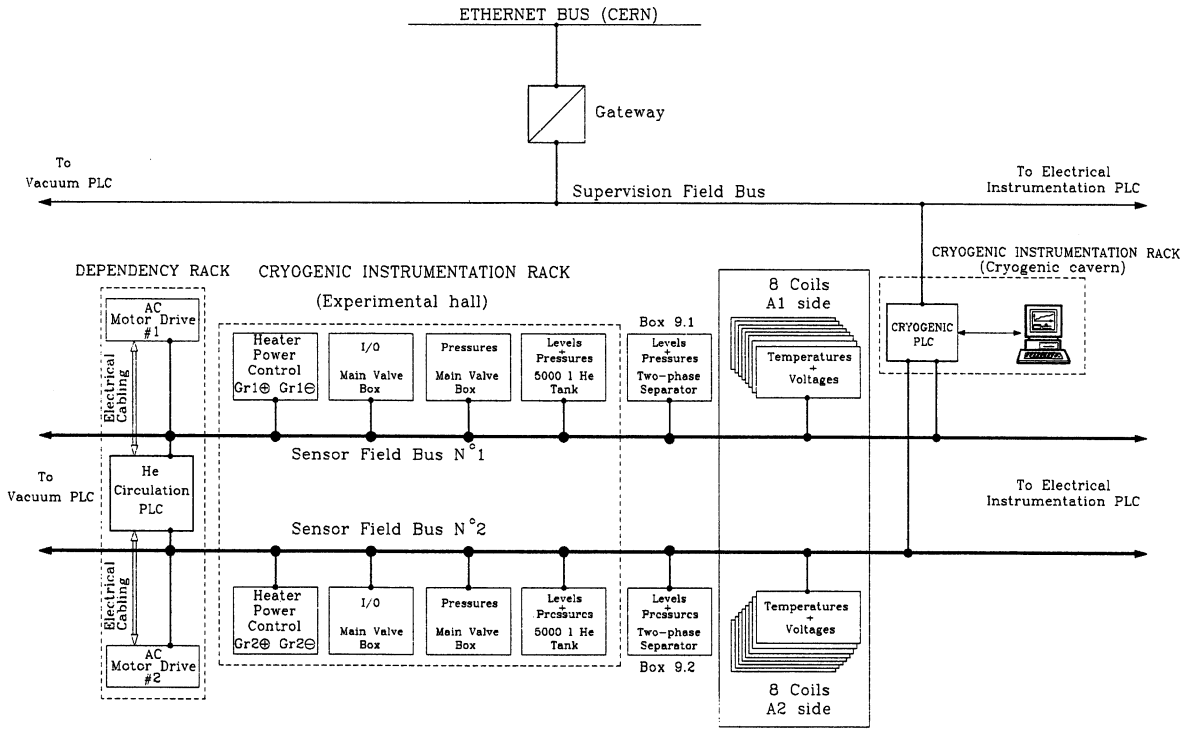

Figure 3