Large Hadron Collider Project

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REFRIGERATION SYSTEM FOR THE ATLAS EXPERIMENT

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Abstract

The proposed ATLAS detector for the 27 km circumference LHC collider is of unprecedented size and complexity. The magnet configuration is based on an inner superconducting solenoid and large superconducting air-core toroids (barrel and two end-caps) each made of eight coils symmetrically arranged outside the calorimetry. The total cold mass approaches 600 tons and the stored energy is 1.7 GJ. The cryogenic infrastructure will include a 6 kW @ 4.5 K refrigerator, a precooling unit and distribution systems and permits flexible operation during cool-down, normal running and quench recovery. A dedicated LN_2 refrigeration system is proposed for the three liquid argon calorimeters (84 m^3 of LAr). Magnets and calorimeters will be individually tested prior to their definitive installation in a large scale cryogenic test area on the surface. The experiment is scheduled to be operational in 2005.

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INTRODUCTION

ATLAS [1] will be the largest of four particle detectors designed to exploit the capabilities of LHC in experiments with colliding protons and heavy ions. All of the experiments use superconducting magnets at 4.5 K [2]. The extent to which ATLAS will use superconducting technology is unprecedented in its size and complexity. This size and complexity is reflected in the associated helium cryogenic system and the refrigeration system needed for cooling the three liquid argon calorimeters. This paper describes the cryogenic infrastructure to be installed at Point 1 of LHC, the refrigeration system and the operational scenarios studied and defined to date. The design of the ATLAS magnets and calorimeters is an international undertaking with contributions from laboratories in Europe, Japan and the USA.

THE TOROIDAL MAGNET COMPLEX AND ITS CRYOGENICS

The Barrel Toroid (BT) and the two End Cap Toroid magnets (ECT's) produce a large volume toroidal magnetic field for the muon spectrometry. The BT is made up of 8 rectangular coils each with a length of 26 m and a height of 5 m. They are symmetrically arranged around the central beam axis and fit within an outer diameter of 19.5 m [3]. Each ECT consists of 8 rectangularly shaped coils housed in a common vacuum vessel which has an outer diameter of 10.5 m and a length of 5 m. The peak field of both toroids is 4 T at a nominal current of 20 kA. Parallel refrigerant flow is used to cool each of the three magnet subsystems [4]. The coils of the toroids are cooled with two-phase helium circulated by means of centrifugal pumps. Each toroid has a dedicated pump backed up by a second identical one in case the first develops a fault [5]. The mass flow rate through the coils under normal operating conditions is 600 g/s for the BT's and 300 g/s for each of the ECT's. Sufficient autonomy for slow discharge of the coils in case of failure of the refrigerator is provided by a 5000 l dewar for the BT and 1600 l dewars for the ECT's. In case of fast discharge stored energies of 1.1 GJ for the BT and 0.25 GJ for each ECT will be dumped in the cold mass of the magnets heating them up to 58 K (BT) and 53 K (ECT's) respectively.

THE SOLENOID AND ITS CRYOGENICS

The solenoid is relatively small compared with the toroids and has a length of 5.3 m and an inner diameter of 2.4 m. It is designed to provide an uniform magnetic field of 2 T at 8 kA for the inner tracker. Supercritical helium from the common refrigerator is sub-cooled in a 250 liter control dewar and expanded by using a J.T. valve to provide the necessary 7 g/s of good quality two-phase helium. The liquid helium in the dewar also serves for secure slow discharge of the magnet. The solenoid is housed in the same vacuum vessel of the liquid argon barrel calorimeter to minimise the amount of material along the particle trajectories.

THE HELIUM CRYOGENICS INFRASTRUCTURE

It is proposed to install a dedicated helium cryogenic plant and the associated infrastructure at CERN's LHC Point 1 (see Fig.1). This consists of:

1) The He screw compressors, the He storage tanks and a recuperation and purification system at the surface level.
2) The cold box and the precooling unit in the underground cryogenics service cavern.
3) The distribution system and the local cryogenics for the four magnet sub-systems in the main detector cavern.

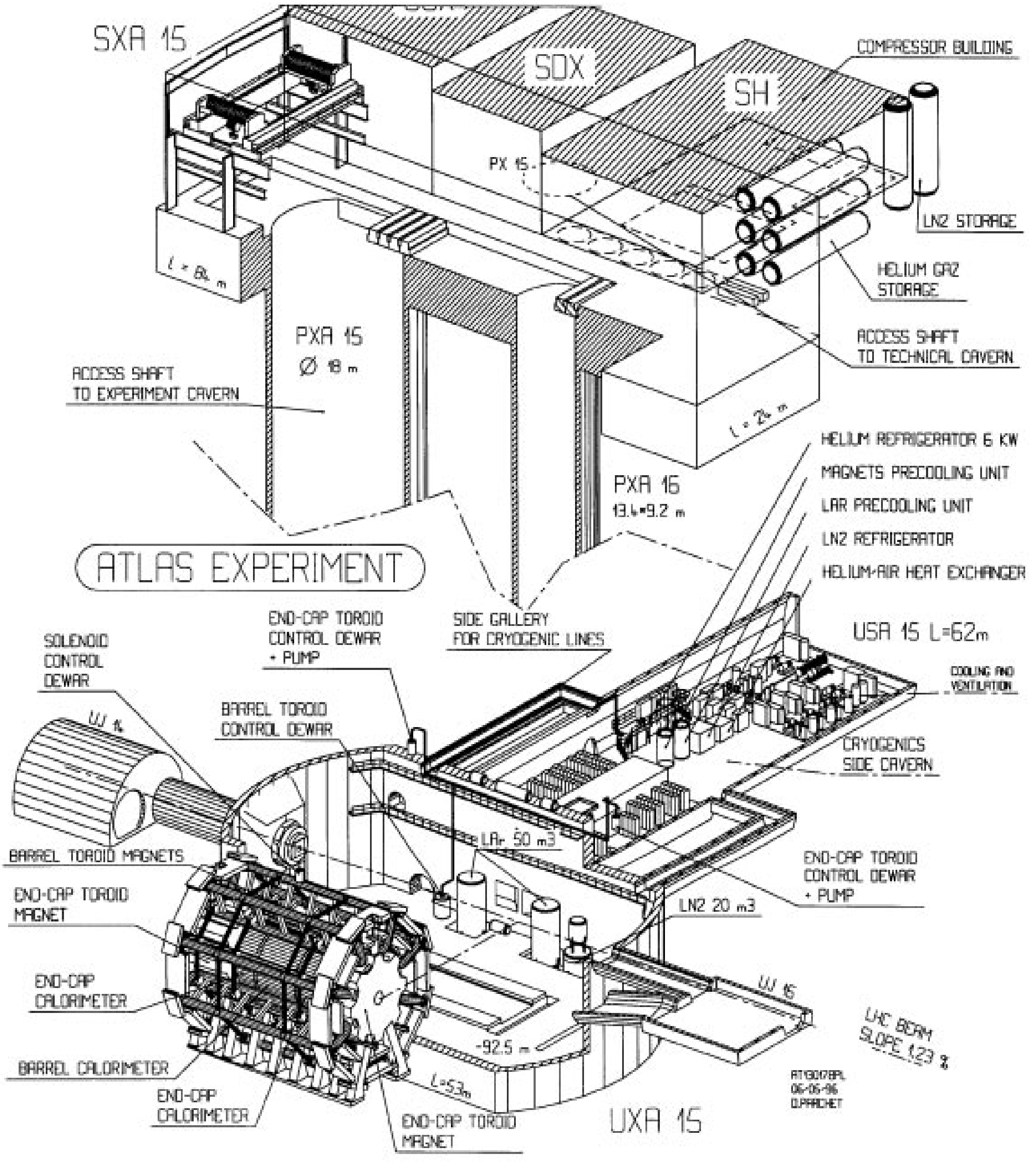

Figure 1 3-D view of the cryogenics areas of the ATLAS experiment, surface buildings, side cavern and the main detector cavern. Cut out view of the detector showing the arrangement of the superconducting magnets and the liquid argon calorimeters.

Based on the thermal budget of the magnets (see Table 1) we presently foresee a refrigerator capacity of 6 kW @ 4.5 K and a compressor flow of 500 g/s (1-20 bar). Detailed studies will be carried out taking into account various scenarios such as precooling baseline operation and recovery from a fast discharge which will permit an optimisation of the thermodynamic cycle and the refrigeration capacity. The thermal budget of the four magnets is 2550 W of isothermal refrigeration at 4.5 K, 10.3 g/s of liquefaction for cooling four pairs of current leads, and 10600 W for the thermal shields (feed 40 K, return 80 K). A dedicated precooling unit with a LN_2/He heat exchanger will be installed for cooling the magnets from 300 to 100 K. The 23 m^3/d of LN_2 required during this phase of the cool down will be supplied from two

50 m^3 storage tanks at the surface. The associated helium mass flow rate will be withdrawn from the compressor/refrigerator circuit.

Helium Cryogenics						Argon Calorimeter Cryogenics				
Baseline operation Conditions										
		BT	2 ECT	Solenoid	Total			Barrel	2 ECC	Total
Liquid volume	m^3				15	Liquid volume	m^3	44	40	84
Cold mass	tons	350	214	5.5	570	Cold mass	tons	130	440	570
Cold mass shield	tons	25	45	0.5	71	Isoth.load 89 K	kW			19.1
Stored energy	GJ	1.1	0.5	0.04	1.7					
Load 40 to 80K	kW	6.3	4.02	0.28	10.6	LN_2 refrigerant flow			m^3/d	14
Load 4.5 K	kW	1.24	1.22	0.09	2.55					
Current leads	g/s	3	6	1.3	10.3					
Total equiv. 4.5 K	kW	2.03	2.13	0.24	4.4					
Refrigerator (with contingency)@4.5 equiv. Compressor mass flow (1-20 bar)				kW g/s	6 500	LN_2refrigerator			kW	25
Cool down operation conditions										
Time 300/100 K (pre-cooling unit) Time 100/4.5 K (refrigerator) (ΔT max = 40K) total				days days days	28 12 40	Time 300 K/89 K (He/LN_2 pre-cooler) (ΔT max = 40K) total			days	40
Average cool-down power He mass flow pre-cooling unit (300-100 K) LN_2 consumption				kW g/s m^3/d	43 220 23					

Table 1: Cryogenics parameters for the refrigeration systems of the ATLAS magnets and calorimeters. BT = Barrel Toroid Magnets, ECT = End Cap Toroid Magnet, ECC = End Cap Calorimeter.

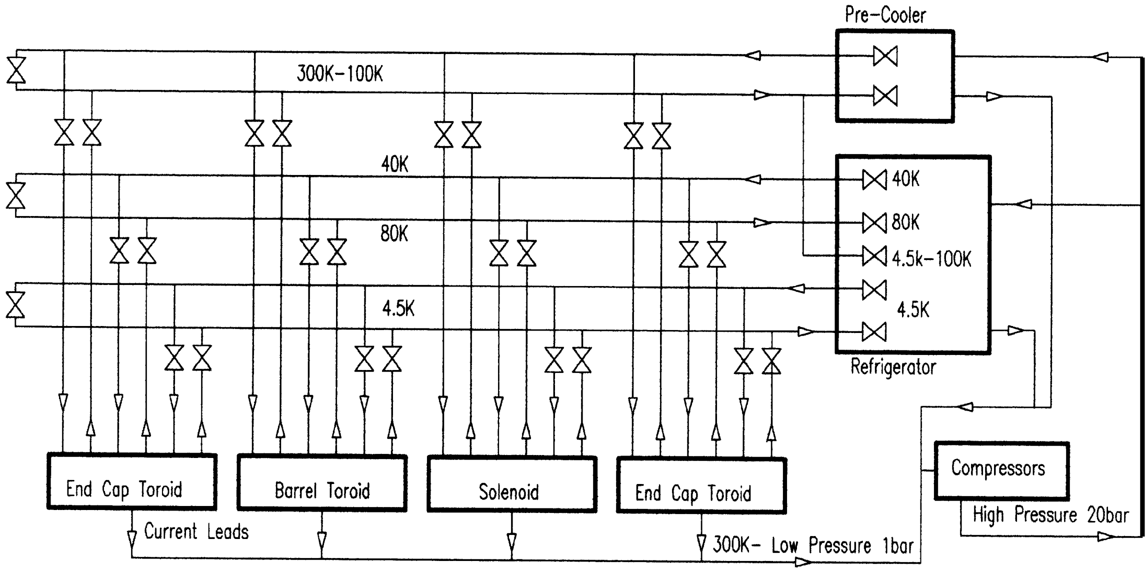

Figure 2 Helium Distribution System for the ATLAS Magnets

HELIUM DISTRIBUTION SYSTEM

The helium refrigerants will be distributed via a low loss transfer line system linking the precooler unit and the refrigerator in the side cavern to the cryogenics equipment in the main cavern. The modular design of this system is shown in Fig. 2 and permits operational flexibility in the cool down, baseline running and recovery modes. Precooling of the feed and return lines for any defined temperature level at baseline load (supercritical He supply at 4.5 K to the coil systems and 40 K/80 K supply and return to the shields) will be carried out using a bypass at the ends of the transfer lines. A similar system will be used for the magnet precooling system (300 K - 100 K). For reasons of thermodynamic optimisation, the enthalpy of the cold return gas will be fully utilised in the refrigerator and/or the precooler. No heaters will be installed for warming up the helium gas flows.

FUNCTIONING

The LN_2 pre-cooler unit will be used from ambient to ~100 K and the refrigerator will be used from ~100 K to 4.5 K. From ambient to ~100 K the thermal limits on the magnets will be a temperature gradient not exceeding 40 K and a cool down rate not exceeding 2.5 K/h.

The modular design of the He distribution system will permit the magnet subsystem to be run under different conditions if required. For example, one magnet could be in cool down mode from ambient while the remaining are already operating at 4.5 K. In another configuration one or more magnet(s) may be in quench recovery mode while the others are kept cold. Recovery time for any quenched magnet subsystem will not exceed four days. Various post-quench situations will be studied and optimal solutions investigated for different operational scenarios**.**

THE LAR CALORIMETERS AND REFRIGERATION SYSTEM

The three liquid argon calorimeters, with a total liquid inventory of 84 m^3 are the barrel electromagnetic calorimeter (dimensions of vessel 4.5 m o.d., length 6.8 m) and the two end cap electromagnetic and hadronic calorimeters (dimensions of each vessel 4.5 m o.d., length 3.3 m). The equipment for the dedicated LAr refrigeration system is located as follows:

1) Floor level: the nitrogen compressor for the LN_2 refrigerator, the LN_2 storage tanks and the helium compressor.
2) The underground cryogenics service cavern: the LN_2 refrigerator (25 kW) and the precooling unit (He/LN_2).
3) The main cavern: the two 50 m^3 LAr storage tanks, the 20 m^3 LN_2 buffer tank and the local auxiliary cryogenics.

Precooling of the calorimeters from ambient temperature to 89 K in 40 days will use He/LN_2 heat exchange. Helium at 1-3 bar will be circulated with a compressor. At operational temperatures the calorimeters will be purged and filled with LAr delivered by truck from the surface area. Internal cooling of the LAr will be done either directly with LN_2 or indirectly with an intermediate LAr circuit (design decision pending) in horizontal heat exchangertubes. The LN_2 refrigerator will provide the cooling for all operational modes (cool down and normal operation at 89 K) of the detectors. The 20 m^3 of LN_2 in the main cavern will be designed to give more than a day of autonomy in case of failure of the LN_2 refrigerator. An additional back-up will utilise the LN_2 (2 x 50 m^3) from the tanks at the surface level. If necessary, the complete liquid inventory of any or all the cryostats can be drained into the 100 m^3 LAr storage tanks near to the detector in the main cavern.

THE ATLAS TEST FACILITY HALL

All the cryogenic components will be tested prior to their final installation in the underground cavern. This will be carried out in a large experimental hall having 10,000 m^2 of surface area which will be converted into a cryogenics test facility permitting individual tests of BT and ECT magnets and the three liquid argon calorimeters. Equipment which will be needed for the test programme includes four test stands for the BT magnets, helium precooler units for the magnets and calorimeters and an existing helium cryoplant with a capacity of 1200 W @ 4.5 K. The stringent schedule, especially the arrival of a pre-series prototype barrel magnet coil with approximately 1/3 of the length of the final magnets will require this test facility to be available in 1999, well before the start of delivery of the series magnets planned for 2001.

REFERENCES

1 ATLAS collaboration, "ATLAS Technical Proposal", CERN/LHCC/94-43, Geneva, 1994.
2 Bremer J., Dauvergne J.P., Delikaris D., Delruelle N., Haug F., Passardi G., Rieubland J.M., Kesseler G., "Cryogenics for CERN Experiments. Past, Present and Future", ICEC 16, Kitakyushu, Japan, 1996.
3 Baze J.M. et al., "Progress in the Design of a Superconducting Toroidal Magnet for the ATLAS Detector of LHC", 14th Int. Conference on Magnet Technology, Tampere, Finland, 1995.
4 Cragg D. , "The Cryogenic System of the ATLAS Experiment End Cap Toroids", ICEC 16, Kitakyushu, Japan, 1996.
5 Mayri C., Curé C., Duthil R., Cragg D., Haug F., Passardi G. , "Barrel Toroid Cryogenic System for the ATLAS Detector", ICEC 16, Kitakyushu, Japan, 1996.
6 Tanaka K., Yamamoto A., Doi Y., Haruyama T., Kondo T., Makida Y., "Cryogenic Design of the ATLAS Thin Superconducting Solenoid Magnet", ICEC 16, Kitakyushu, Japan, 1996.