The Cryogenic System of the ATLAS Experiment End Cap Toroids

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The ATLAS Experiment proposed for the Large Hadron Collider will use a toroidal magnet system to achieve high efficiency muon momentum resolution. The End Cap Toroids (ECT's) are designed to provide bending powers in the range 4-8 Tesla-metres over the rapidity span 1.5-2.8 in the important forward/backward regions. Each ECT will have an outer diameter of approximately 11 metres, a length of 5 metres and a weight of 190 tonnes. They will each have eight separate coils and a single integral radiation shield which will all be contained in a common cryostat.

INTRODUCTION

The muon spectrometer of the ATLAS general-purpose pp detector will be based on the configuration of large superconducting air-cored toroids shown in Figure 1 and will consist of a long barrel toroid (BT) and two inserted ECT's to generate the large field and strong bending power required. One ECT is shown withdrawn from its normal operating position to allow access to internal detectors. The Rutherford Appleton Laboratory will be responsible for the design of the ECT's [1] and this paper describes the cryogenic design.

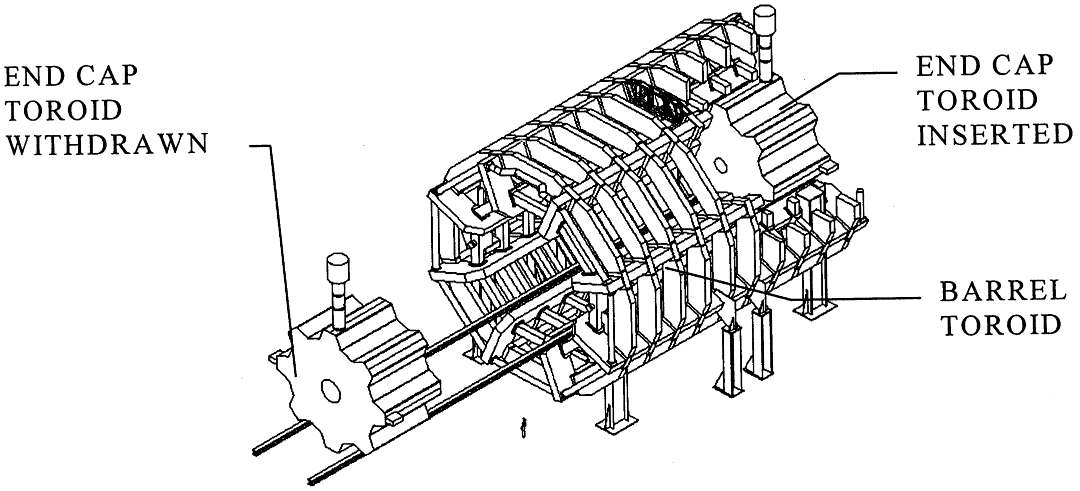

Figure 1 ATLAS superconducting toroid magnet system.

The ECT's will be designed to provide bending powers in the range 4-8 Tesla metres over the rapidity span 1.5 - 2.8 in the forward/backward regions. While the BT design will be based on an open structure with 8 coils in individual cryostats the ECT design will be based on mounting 8 coils in a single large vacuum vessel approximately 11 metres in diameter and 5.6 metres in length.

HELIUM REFRIGERATION SYSTEM

The ATLAS helium refrigeration system will supply the BT, the two ECT's and a centrally located solenoid. It will be designed to have the capacity to cool the whole ATLAS magnet system down in 40 days and to supply the peak demand required during base temperature operation, i.e. all the magnets charging at the same time. In order to give the necessary flexibility of operation, the system will be divided into two discrete components: a liquid nitrogen cooled pre-cooler and a helium refrigerator.

The pre-cooler covers the temperature range from 300K to ~100K and will cool down and warm up the magnets: - both relatively infrequent processes.

The helium refrigerator will cover the temperature range below ~100 K and will supply helium gas at 40K to the radiation shields and supercritical helium at ~4.5K to the coil system during cool down and operation at base temperature.

CRYOGENIC DESIGN

The main structural components of an ECT are shown in Figure 2. The current leads, which are not shown, will be installed vertically inside the services turret.

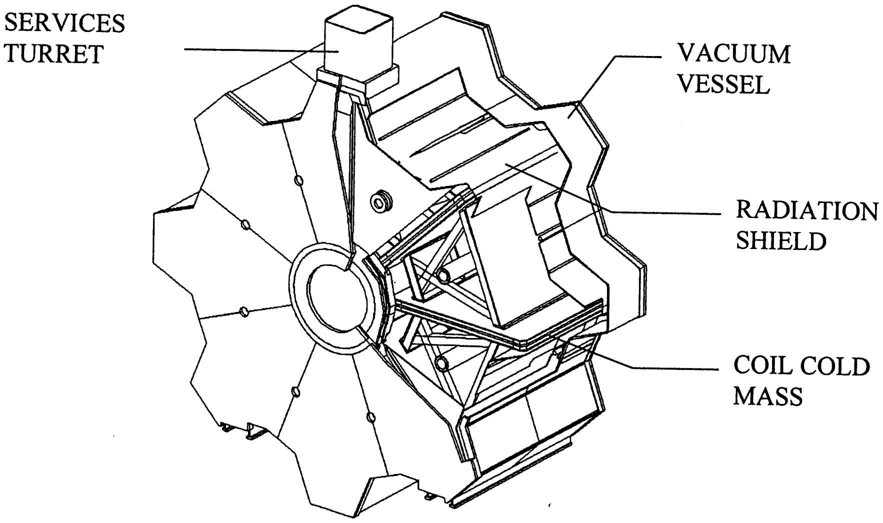

Figure 2 Main cryogenic components of an ECT.

The heat load into the radiation shields will be minimised by using 30 layers of superinsulation. It will not be considered necessary to superinsulate the coil structure, only to reduce the emissivity of the surfaces by mechanically polishing the metal components and by covering the exposed plastic surfaces with aluminium foil. This has proved to be the most cost effective solution in the past for large cryogenic systems and will give a low value for the radiative heat leak into the system [2].

The current leads will be designed to take the high pressures developed during a fast discharge and will be cooled directly by using two-phase helium returning to the buffer/storage dewar from the coil cooling circuits.

The cryogenic parameters of a single ECT cryogenic system are given in Table 1.

Cool Down

During cool down from 300K to ~100K it will be important to avoid thermally induced stress caused by imposing too high a temperature differential across the cold mass. The limits chosen for the ECT's are a cool down rate not to exceed 2.5 K/hour and a temperature differential not to exceed 40K. In order to simplify the control system and to avoid problems met by cooling the radiation shields and coils separately their cooling circuits will be connected in series during this period. The mass flow rate required from the pre-cooler to cool an ECT down from 300K-100K in 33 days will be ~40 grams/second.

Table 1 Cryogenic parameters of a single ECT.

Parameter	Radiation Shield	Coil
Cold mass	22500 kg (22.5 tonnes)	107000 kg (107 tonnes)
Radiation heat load	1380 W	300 W
Conduction heat load from supports	330 W	29 W
Coil charge /discharge	-	56 W
Heat load from local cryogenics	75 W	25 W
Maximum heat load from helium pump	-	125 W
Operating current	-	20000 A
Current lead helium consumption	-	0.003 kg/s (90 litres/hr)
Refrigerator demand at base temperature	0.0086 kg/s (8.6 gm/sec)	0.028 kg/s (28 gm/sec)
Helium pump mass flow rate	-	0.28 kg/s (280 gm/sec)

Below 100K these thermal restrictions will not apply so it will be possible to connect the radiation shields and the coils directly to the refrigerator, cooling down the shields with 40K helium gas and the coils with supercritical helium. The coils will be cooled in the same way during the recovery from a fast discharge.

If the helium refrigerator capacity needed to run the ECT coils at base temperature is used to cool them down from ~100K and recover them from a fast discharge the cool down times will be ~7 days and ~2 days respectively.

Base Temperature Operation

The radiation shields will be designed to run with a temperature differential across them of 40K, i.e. they will return helium to the refrigerator at a temperature of 80K.

In order to avoid a fast discharge when a refrigerator fault occurs, the coils will be cooled during base temperature operation by pumping two-phase helium round the cooling circuits from a buffer/storage dewar. The two phase helium will be produced by expanding supercritical helium from the refrigerator through a JT valve. Flow instabilities in the coil cooling circuits will be prevented by pumping the two-phase helium at a mass flow rate which will return it to the dewar with a liquid content of not less than 90% (quality factor 0.1).

CRYOGENIC SYSTEM

The proposed layout of the cryogenic system is shown in Figure 3.

Internal Cryogenic System

The internal cryogenic system of an ECT will not contain a significant volume of helium and will consist simply of the current leads and the cryogenic cooling circuits of the radiation shields and the coils.

Local Cryogenic System

The local cryogenic system of an ECT will consist of a valve box, a buffer/storage dewar, two helium pumps and the connecting transfer lines. Because space within the experimental cavern will be at a premium and high magnetic fields will be present in the detector region, the valve boxes, buffer/storage dewars and the helium pumps will be placed at the wall of the cavern on a high level gantry. The proposed flow diagram of the local cryogenic system for a single ECT is shown in Figure 4.

The valve box will contain all the control valves required to cool down/warm up and run an ECT at base temperature and all the pressure relief valves needed to protect the system during fault conditions and fast discharges of the coil.

In the event of a refrigerator failure the buffer/storage dewar will have sufficient capacity to enable the coil to be discharged from full current in about 2 hours.

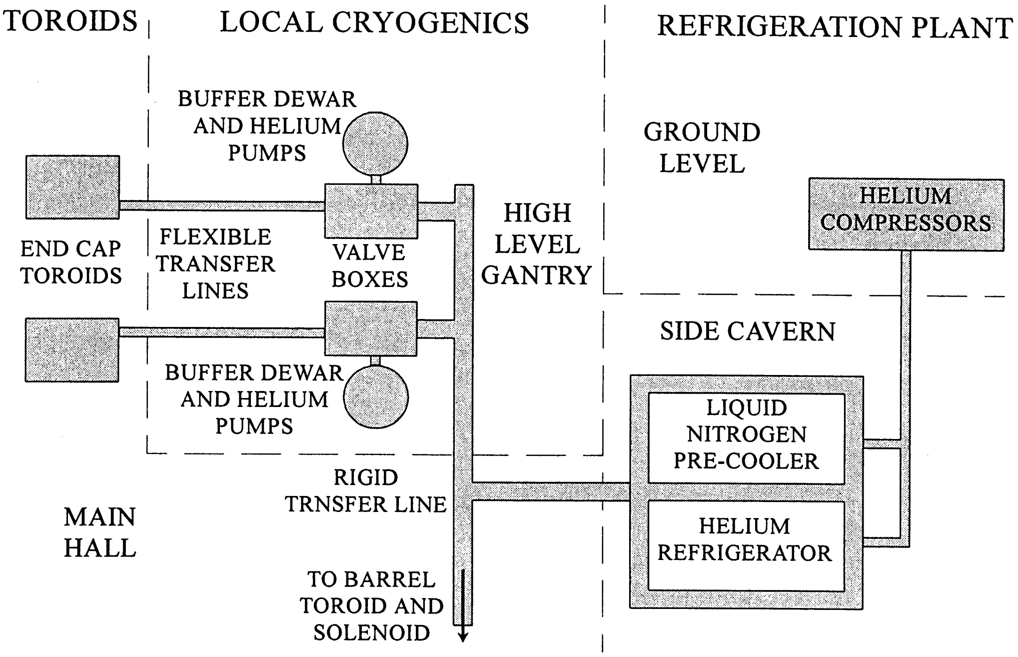

Figure 3 Layout of the ECT cryogenic system.

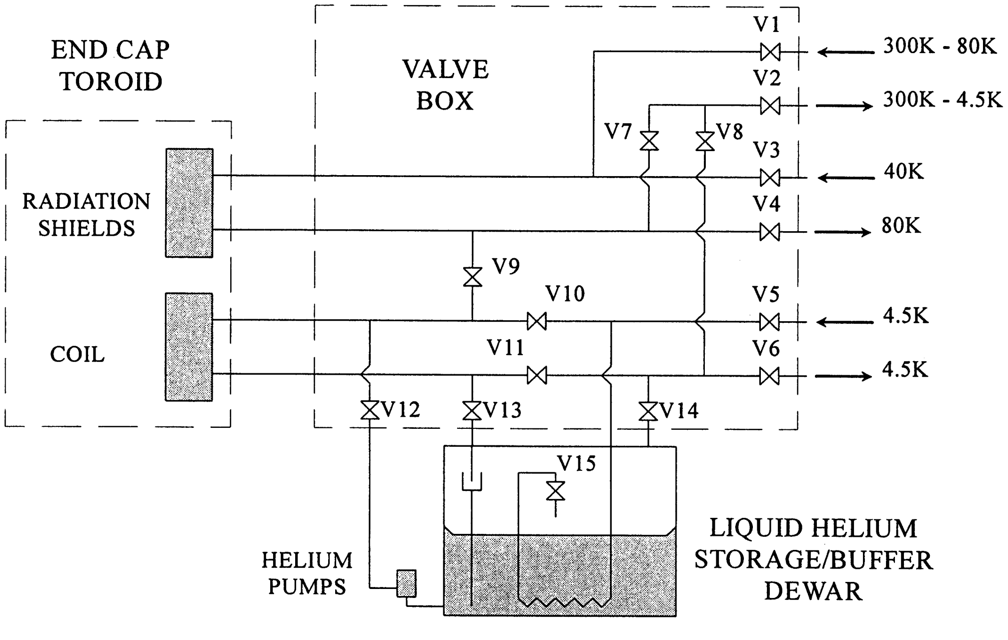

Figure 4 Flow diagram of the local cryogenic system for a single ECT.

The two helium pumps will be proprietary centrifugal pumps and each will have the capacity necessary for normal operation. One will be on line while the other will be held in reserve should the first develop a fault.

Since the ECT's will need to be moved out of their operating positions during shut down periods they will be connected to their respective valve boxes by flexible cryogenic transfer lines. All the other transfer lines will be of the conventional rigid, tube-in-tube variety.

REFERENCES

1 The AECT reference design report, RAL report AECT/55/96 (1996).
2 Cragg, D., Thermal and vacuum insulation for large cryostats, RAL report AECT/56/96 (1996).