The CERN Cryogenic Test Facility for the Atlas Barrel Toroid Magnets

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Abstract--The superconducting magnet system of the ATLAS detector will consist of a central solenoid, two end-cap toroidal magnets (ECT) and the barrel toroid magnet (BT) made of eight coils symmetrically placed around the central axis of the detector. The magnets will be tested individually in a 5000 m2 experimental area prior to their final installation at an underground cavern of the LHC Collider. For the BT magnets, a dedicated cryogenic test facility has been designed which is currently under the construction and commissioning phase. A liquid nitrogen pre-cooling unit and a 1200 W@4.5K refrigerator will allow flexible operating conditions via a rather complex distribution and transfer line system. Flow of two-phase helium for cooling the coils is provided by centrifugal pumps immersed in a saturated liquid helium bath. The integration of the pumps in an existing cryostat required the adoption of novel mechanical solutions. Tests conducted permitted the validation of the technical design of the cryostat and its instrumentation. The characteristics of one pump were measured and pressure rise of 300 mbar at nominal flow of 80 g/s confirmed the specifications.

Index Terms--LHC, ATLAS, Barel Torroid magnets, Cryogenic Test Facility, immersed liquid He pumps

I. INTRODUCTION

ATLAS (1) will be one of four particle detectors designed for the exploitation of the CERN's 27 km circumference LHC Collider for experiments with protons and heavy ions. The detector and its superconducting magnet system operating at 4.5K are of unprecedented size and complexity. A preliminary description of the associated cryogenic system is given in (2) together with an overview of the cryogenics for the liquid Argon calorimetry .

The magnet system consists of the Barrel Toroid magnet (BT) made of eight, 26 by 5m, individual racetrack coils placed around the central detector axis, two end cap magnets (ECT) of 10.5 m diameter and a central solenoid (CS). The magnet system is described in detail in (3) and the most recent design studies of the cryogenics scheme is given in (4), presented at this conference.

All the individual magnet subsystems and components must be tested in a large experimental area prior to their final installation in the underground cavern. A test facility has been designed specifically for the "series" testing of the 8 BT coils and a pre-series prototype of reduced size. In addition studies are pursued to extend the use of this plant for the testing of the ECT's while the CS will be tested with an independent plant and is not subject of this paper. A general description of the toroid magnet test facility is given in (5), presented at this conference.

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II. THE MAGNET TEST FACILITY

Fig. 1 is a top view of the simplified layout showing two individual barrel toroid magnets on their respective mechanical support structure. However, only one magnet at a given time will be cooled and tested. The ECT's will be installed at the outside limits of the building in case this solution is adopted (5).

Three transfer lines distribute the cryogens from the distribution valve box to the individual magnet at test. For the two BT test benches this will be done from the floor level where these lines terminate each with 4 individual flexible transfer lines connecting to the "cold turret" serving as the interface to feed the magnet with coolant for the cold mass and the thermal shield. On the top of the magnet the

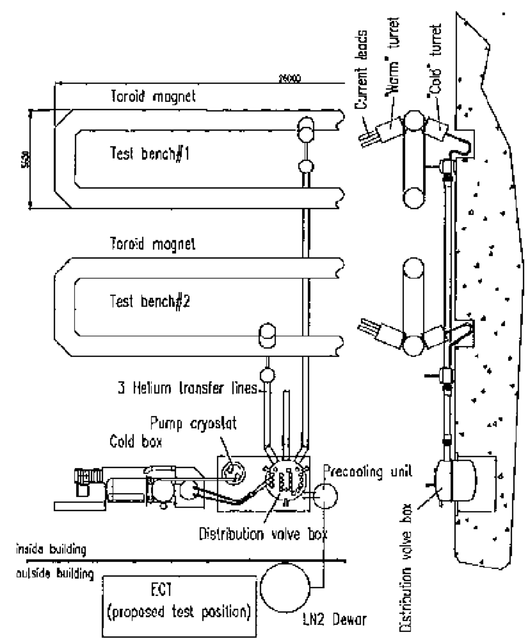

Fig.1 Simplified layout of the magnet test facility showing test positions and cryogenic equipment

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"warm turret" houses the 20 kA current lead pairs. The turrets are temporarily installed during the test campaign of an individual magnet.
The pump cryostat connects to the distribution valve box and to the cold box of the 1.2kW refrigerator via transfer lines and is installed in between them. The precooling unit connects directly to the distribution valve box. Two independent compressors feed the cold box and the precooling unit respectively and are installed at distances between 50 and 100 m (fig.2).

III. Cryogenic requirements

Table 1 lists the basic cryogenic parameters of a single barrel toroid magnet. The cool down time of the cold mass from ambient to baseline temperatures is approximately one month. Maximum allowed temperature gradients are 40 K in the temperature range between 300 and 100 K. The magnets design teams have chosen an indirect cooling principle done via pipes attached to the cold mass and the thermal shields.

	Cold mass	46	tons
	Shield mass	3	tons
Cool down	Cool down time 300/100 K	20	days
	Average cooling power	5	kW
	Cool down time 100/4.5 K	10	days
	Average cooling power	1	KW
Baseline Operation	Thermal load@ 4.5 K	150	W
	Shield load	880	W
	Current leads	3	g/s
	LHe flow @ 4.5 K	80	g/s

TABLE 1: Cryogenic parameters of BT magnets

At 4.5 K baseline operation a flow of 80 g/s of saturated liquid helium isothermally cools the expected load of 150 W of the cold mass. The vapour quality at the outlet of the magnet circuit shall be below 10 % of the total mass flow. Three g/s of helium is needed for the current leads cooling. The thermal shields designed for 40 K inlet and 80 K outlet temperature requires approximately 880 W.

IV. The cryogenic system

The cryogenic system makes use of individual equipment considered as "building blocks". These are the 1.2 kW refrigerator, the LN2 precooling unit with a dedicated compressor, the pump cryostat housing two immersed centrifugal pumps, the distribution valve box and three transfer lines feeding the test benches. A principle simplified flow scheme is shown in fig. 2.
The cool down is done in two distinct steps. The LN2 precooling is applied for the duty 300K/100K. In this case the thermal shield and cold mass are connected in series through the valve box where the "switching" is made.

At 100 K the precooling unit is disconnected and the refrigerator is connected in turn to continue the cool down of both the cold mass and the shield in parallel. The cold mass receives the refrigerators' J.T. flow directly via a three way valve serving as bypass in the cryostat and, the thermal shields lines are connected to the respective refrigerator ports which supplies 60 K helium.
After complete cool down to 4.5 K liquefaction initiates in the cooling circuits of the magnet. The two-phase flow is returned to the cryostat and the liquid surplus separated to fill the cryostat.
As soon as the required liquid level in the cryostat is attained the three-way valve can be switched to normal operation position, i.e. the refrigerator is connected to the cryostat only to maintain the liquid level and pressure and

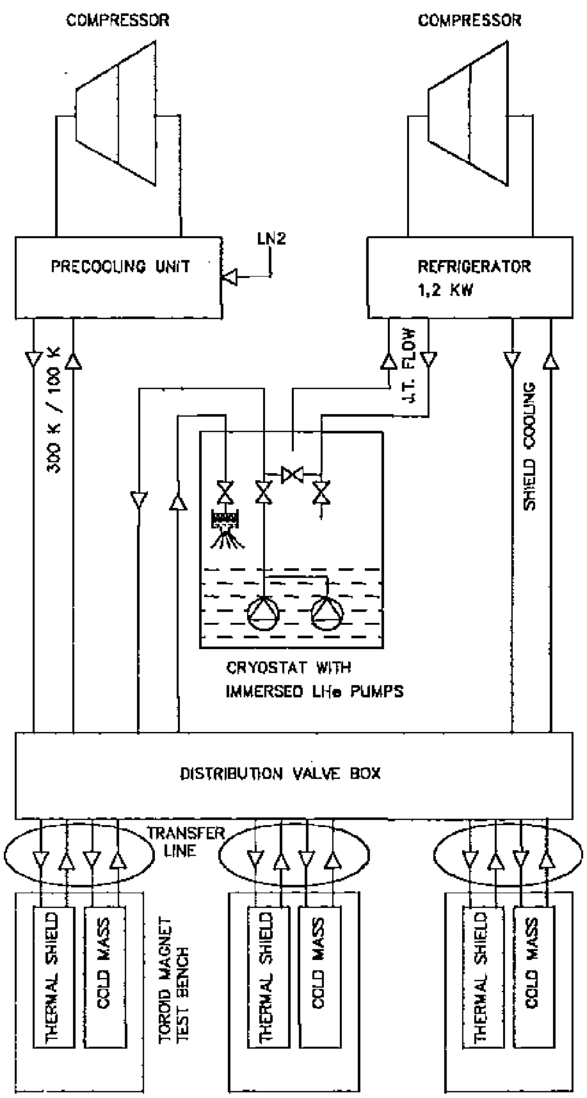

Fig. 2: Simplified flow scheme of the complete cryogenic plant

the centrifugal pump circulates the required liquid flow to the magnet which corresponds to the baseline operation conditions.
The adopted configuration allows in addition to the testing of one magnet at 4.5K the parallel cooling down from ambient temperature to 100 K of a second one.

V. The Pump Cryostat

The pump cryostat is designed to house two independent immersed centrifugal pumps, one being redundant. An existing vertical cryostat was used, modified and equipped for the specific needs. The two pumps were specified for the supply of 80 g/s at pressure heads of 300 mbar and with a maximum shaft length.
For mechanical reasons the shaft length must be kept below 1 meter. Therefore a specific anticryostat of novel design was fabricated. This anticryostat permits the suction inlet to the pump impeller to be as close to the bottom of the cryostat sump as possible while the electrical motor is outside the cryostat at ambient temperature and cooled by air.
The reason for this design feature is to make use of the full liquid helium inventory of the cryostat in case of failure of the refrigerator allowing slow discharge of the magnet at test. In fact the cryostat inventory of 500 l permits more than one hour of autonomy covering the thermal losses of the magnet and the cryogenic equipment without refrigerator supply. This is twice the time required for a slow discharge of a magnet. In addition due to the "deep" integration of the pump, the suction pressure head is maximum at filled cryostat, hence, minimising any potential risks of cavitation.
At the outlet of the pumps a tube heat exchanger immersed in the bath is used to subcool the flow. The mass flow rate is measured with a venturi type flow meter equipped with a cold pressure transducer. This flow meter can be calibrated, and re-calibrated in case of necessity, with a turbine flowmeter used as secondary standard installed in the cryostat in an internal bypass.
The fraction of helium vaporised in the magnet is measured by a specifically designed capacitance-type-void-fraction meter installed at the return path in the cryostat. In combination with the mass flow rate this measure permits to evaluate the thermal budget of each individual barrel toroid magnet.

VI. Tests Results

Currently we are in the construction phase and expect the cryoplant to be completed by the end of the year 1999. So far the refrigerator and the pump cryostat with one integrated centrifugal pump have been commissioned and are operational.
Extensive test campaigns have been carried out in order to validate the technical solutions adopted for the cryostat design and its particular instrumentation. Calibrations of the venturi flow meter were made. Simulations of the thermal

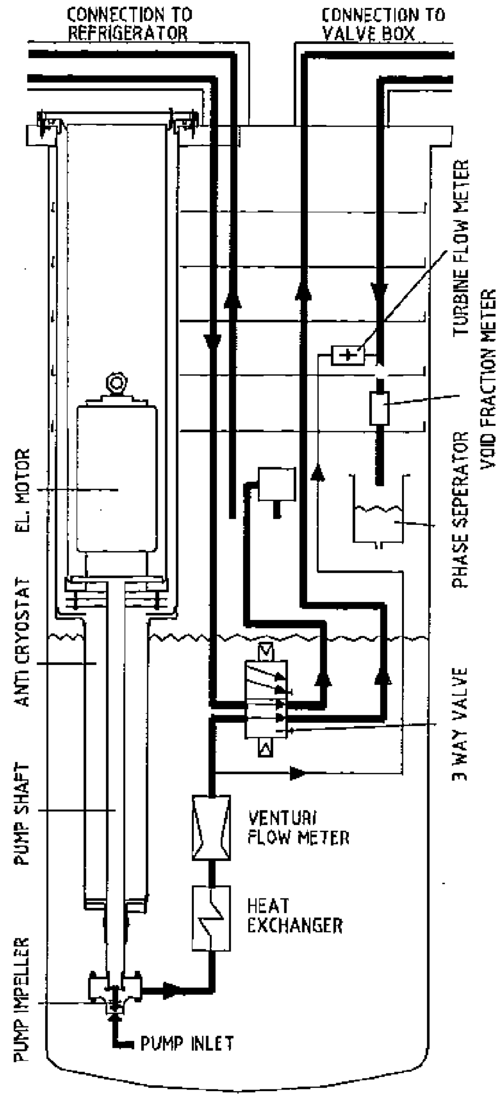

Fig.3 LHe cryostat showing one integrated centrifugal pump with its anticryostat and instrumentation

load of a magnet have been carried out with an electrical heater temporarily installed in a transfer line used as bypass to vaporise part of the liquid flow circulated by the pump. The response of the void fraction meter and the complete cryogenic system to heat loads in excess of 500 Watts were investigated.
Pump pressure rises versus mass flow rate were measured for different speeds as presented in fig. 4. The maximum pressure rise of 300 mbar was found at nominal speed of 3950 rpm with flow rates of 80 g/s corresponding to the specified values. At pressure heads of slightly below 200 mbar the flow rate was in excess of 130 g/s. the overall "flat" pump characteristics are an advantage for our application to obtain rather stable operation conditions.
In addition start/stop tests of the pump were conducted with the cryostat at full, decreasing level and also when almost empty. It was found that only a few centimetres of

hydrostatic head at the inlet suction side were sufficient for the pump to operate. Neither priming problems nor cavitation occurred and the pump would almost immediately provide the full mass flow corresponding to the respective speed and pressure rise as indicated in fig.4. These results confirm the measurements and studies made at the NHMFL in a similar pump cryostat configuration (ref. 6).
The thermal losses of the cryostat with one integrated anticryostat for the respective pump were measured to be less than 10 Watts. This is a good result considering that the liquid level is almost at the same height as the warm motor drive of the pump.
The contribution of the centrifugal pump to the thermal losses at nominal design conditions, i.e. pressure rise 300 mbar and mass flows of 80 g/s, were measured to be 45 Watts. This corresponds to an isentropic efficiency of approximately 40 % of the pump.

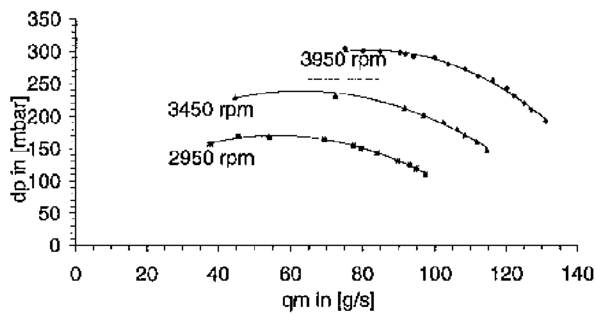

Fig. 4 Characteristics of the centrifugal LHe pump

CONCLUSIONS

A dedicated cryogenic test station for the ATLAS superconducting barrel toroid magnets has been designed and is currently in the construction and commissioning phase at CERN. Its individual equipment allows versatility during the commissioning phase and operation. Until now the refrigerator and the pump cryostat housing one immersed centrifugal pump in a novel configuration have been commissioned and extensive tests with the associated instrumentation conducted. The results obtained, in particular with the immersed pump system, confirm the technical choices and design made.

ACKNOWLEDGEMENTS

We acknowledge the contribution and assistance of J. Metselaar, Y. Drouyer, T Dorenbos and A. Park. We thank J. Bremer for the participation to the pumps testing and M. Pezetti, D. Legrand for upgrading the control system and G. Cuccuru for commissioning and running of the cryoplant. Particular thanks are due to S. Junker and I. Intidam for the instrumentation development and for the conducting of the measurements and to D. Hagedorn for technical advice.

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