The ATLAS Magnets Test Facility at CERN

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Abstract --**The magnet system for the ATLAS detector at CERN consists of a Barrel Toroid (BT), two End-Cap Toroids (ECT) and a Central Solenoid (CS). The overall dimensions of the system are 20 m in diameter by 26 m in length. Before underground installation all coils will be tested on surface in a magnet test facility which is under construction. Moreover two model coils are tested as well as subsystems. In this paper the design and construction of the test facility is presented.**

I. INTRODUCTION

The ATLAS Magnet System [1,2] comprises the superconducting magnets, the power supply system, the cryogenics system, the vacuum system and the control and safety system. The magnet system has overall dimension of 26 meters in length and 20 meters in diameter (see Fig. 1). The superconducting magnets comprise the Toroidal Field (TF) magnet system with the Barrel Toroid and the two End-Cap Toroids and the Central Solenoid. Each of the three toroids consists of eight coils connected in series, with flat pancake type of windings, assembled around the beam axis with an offset angle of 22.5^0 between the BT and ECT systems, in order to optimize the bending power in the available space. A model coil of the Barrel Toroid of reduced length, the B0 model coil, is under construction to qualify the manufacturing cycle and related techniques .The Central Solenoid is a single layer coil wound internally in a supporting cylinder and enclosed by the common cryostat of the Liquid Argon Calorimeter. Aluminum stabilized NbTi/Cu superconductor cooled at 4.5 K by liquid Helium forced flow and glass fiber-epoxy resin insulation are the main components of the coils. A 21 kA common TF power system and an 8 kA CS power system with correspondent quench protection systems are implemented.

In order to verify the construction concepts on B0 and thereafter the correct operation of the other coils, the tests must represent the real configuration. The infrastructure required to perform the tests comprises: a rather complex cryogenic plant with a He refrigerator, a pre-cooling unit, a cryostat with integrated immersed centrifugal pumps for liquid He flows above 80 g/s to cool the magnet cold masses and a distribution system; the vacuum system with a pumping system able to provide 10^{-4} mbar; the electrical system for coil energizing with a 6V/24kA power supply; appropriate quench protection units as well as systems for control and diagnostics.

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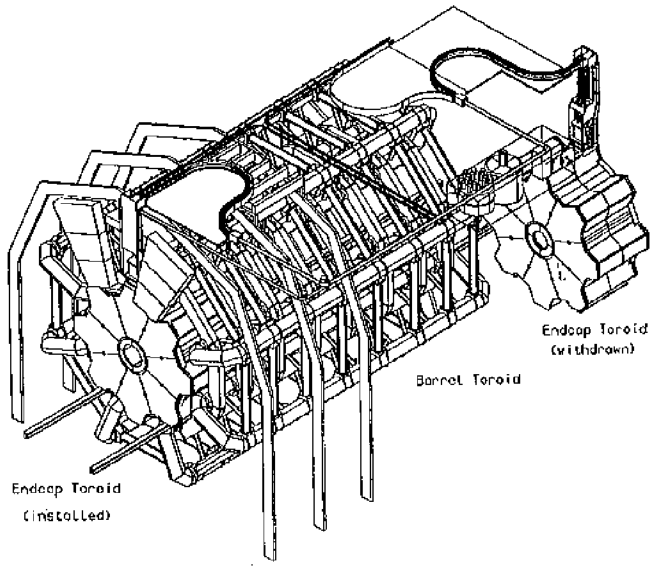

Fig. 1. The ATLAS Magnet System.

Preliminary test of the B0 coil with a magnetic mirror to simulate the electromagnetic load and the full set of instrumentation is planned by summer 2000. Due to the exceptional size of the BT system, each coil will be individually tested on the ground at nominal current with the magnetic mirror so as to reproduce the actual load, before lowering them down in the cavern. Each of the two ECT magnets and the CS magnet will be fully assembled and tested on the surface, before the installation as complete systems in the cavern.

II. THE B00 AND B0 MODEL COILS

The first coil to be tested is the B00 model coil planned for beginning of the year 2000. The main purpose of the B00 model coil is to test all types of ATLAS superconductors in the operating conditions to study ramp losses, stability and quench propagation. Moreover it serves to commission the test station.

The B00 includes:

- Double pancake winding made with BT conductor;
- Double pancake winding made with ECT conductor;
- Single pancake winding made with CS conductor.

An Al coil casing with glued Al alloy tubes for cooling of the cold masses by liquid He is implemented.

The next coil, the B0 model coil, is a test-model of the BT coils with the same design and construction procedures, so as

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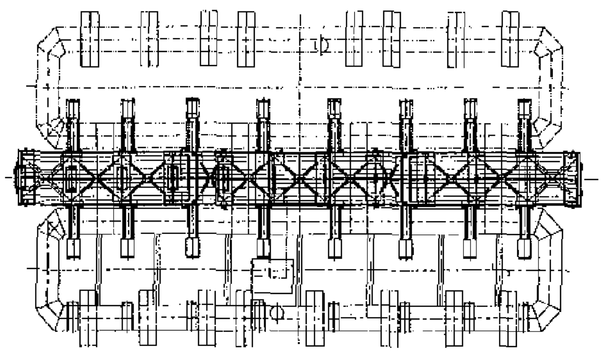

Fig. 2. The 2 BT test benches: top view. The magnetic mirror with its support structure is visible in the middle.

to validate the manufacturing feasibility of the coils. The width and cross section of the B0 coil are the same as for the BT coils, while a reduced length of 9 m was chosen to reduce the cost and the test requirements.

To have as many information as possible many diagnostics and instrumentation are implemented in the B0 coil, such as temperature sensors, voltage taps, pick-up coils, quench heaters, point heaters, strain gauges, hall probes in the joints, superconducting quench detectors, Rogowski coils, acoustic probes and positioning sensors. Moreover diagnostics are required also in the external services, namely He flow sensors on current leads, current leads heaters, DCCT, power supply readings, cryogenics readings, vacuum readings and water flow readings.

The test of B0 with the magnetic mirror is performed only in the horizontal position. In fact in the inclined positions, simulating the real orientation of the BT magnets, only a 5% contribution to cold-to-warm support forces is given by gravity. For testing the cold mass supports and the internal cryogenics a turnover test without magnetic mirrors is sufficient to simulate the loads. This is also required as an assembling and handling exercise.

A detailed test plan is being prepared in order to verify and control the following main issues:

- Thermal cycling between 300 K and 4.5 K and measurements of the related thermal gradients and electrical properties;
- Current cycling up to the current of 24 kA with operation at various current levels and verification of the mechanical stresses in the entire structure and of the safety of the fast and slow discharge procedures;
- In each of the preceding phases, verification of the ground insulation, measurement of the inductance and of the potential in the pancakes for the detection of any internal changes and check of any mechanical disturbances by acoustic sensors;
- Magnetic field measurements.

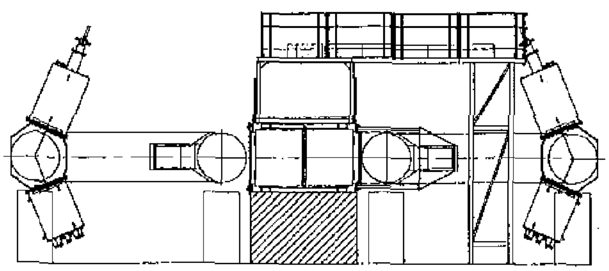

Fig. 3. The two BT test benches: lateral view.

The test of B0 is of the utmost importance because it allows checking the proper functioning of both the cryogenic, electrical and mechanical sensors and the control, safety and data acquisition systems foreseen for the toroids.

III. The ATLAS Magnet System

A. Barrel Toroid

Due to the exceptional size of the BT magnet system, it is not feasible to assemble and test the integrated system on surface, before installation in the underground cavern. Therefore each coil after integration will be individually tested on surface and then lowered down into the cavern for the final assembly of the toroid. Two temporary turrets are installed for the test campaign on each coil, a cold turret which connects to the cryogenic transfer lines through flexible lines and a warm turret which connects to the bus bars via 24 kA current leads. Feeding of the He is preferably done from the bottom, so as to facilitate the distribution in the internal cooling tubes. The magnetic mirror is installed between two coils and held in position by a dedicated support structure, so as to simulate the actual electromagnetic tension load 1280 tons experienced in the real configuration (see Fig. 2 and Fig. 3). The time schedule foresees 2.5 years for the test of eight BT coils starting in spring 2001, with 5 or 6 months time allocated for each magnet. This requires work to be done in parallel in the two test benches.

B. End-Cap Toroids

The ECT (Fig. 4) will be fully tested before transfer to the ATLAS cavern. A test outside Hall 180 is foreseen using the same test facility as for BT coils. The cold masses and vacuum vessels are fully assembled and tested at 80 K in Hall 191. Then they are transferred to the test station position. The cryogenics transfer lines and the bus bar lines will be routed outside Hall 180 probably from the top and attached to the special service turret of the ECT.

The main diffusion pumps and all the control, monitoring and safety cabling are connected to the service turret. The test time allocated for the End-Cap Toroids is 1.5 years starting form the beginning of the year 2003.

C. Central Solenoid

The CS and Liquid Argon Calorimeter are assembled in a common cryostat. A full excitation test of the coil is done at the coil manufacturer side in a temporary cryostat but already assembled on its final inner cylinder. The power supply, the

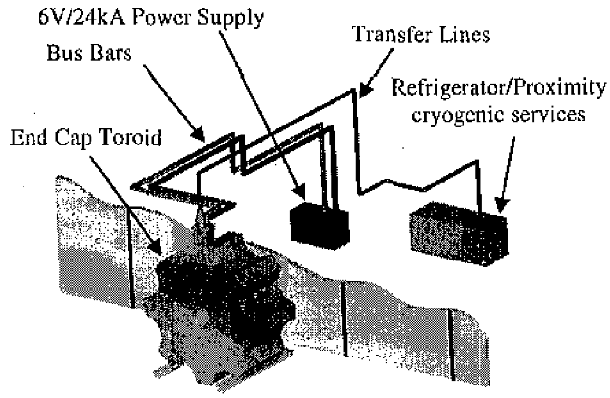

Fig. 4. ECT test station.

control dewar and MCS/MSS systems are as closely as possible to the final ones. Thereafter it is sent to CERN and tested fully integrated with the Liquid Argon Calorimeter in Hall 180. A complete separate infrastructure is required for the test. The excitation test at "Toshiba", Japan is planned by the summer of the year 2000, while the test at CERN starts at the end of 2002.

IV. Test Station

The assembly and testing of all the coils require an important infrastructure in terms of a hall space, hall height, lifting capacities and services. The West Area at CERN meets such requirements (see Fig. 5). Building 180 has a space available for the ATLAS magnets of 7300 m^2. This space just meets the requirements for the test and the assembly of the BT and CS magnets, while the ECT magnets will be assembled in Hall 191 and tested outside Hall 180. Two cranes with a capacity of 40 and 60 tons cover the whole area of Hall 180. The capacity of 100 T is necessary to lift 1 BT magnet with support structures and lifting tools.

The BT coils are the most demanding in terms of space.

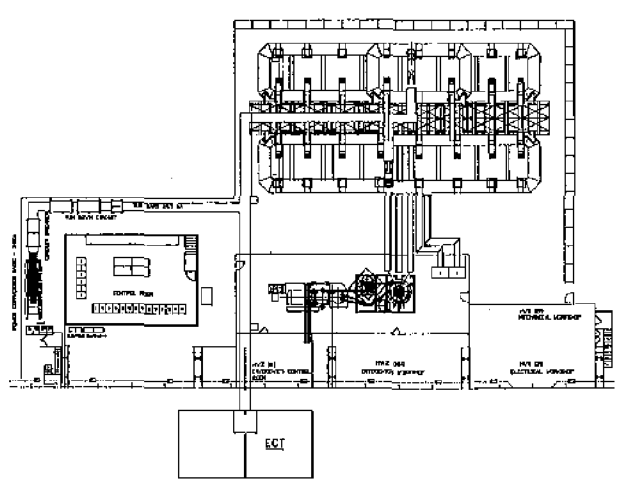

Fig. 5. The test station in Hall 180 at CERN

After manufacturing of the coil components, they will be delivered to CERN ready for integration, which consists of the installation of the cold mass in the vacuum vessel with all the related components. The BT test station comprises two test benches; the cryogenic and power supply systems with related control rooms and workshops; the group of pumps of the vacuum system and the magnet control room. First B00 will be delivered to CERN fully assembled and its test is planed in the bottom test bench (see Fig.5). Then the B0 coil will arrive and will be tested in the top position. The same test equipment in terms of external services will be used for the test of the ECT magnets fully assembled, while the CS coil requires a separate system. Three transfer lines distribute gaseous and liquid helium from the distribution valve box to the individual coils with flexible lines at the BT cryogenic supply turret and the ECT service turret. Bus bar lines distribute the current from the power supply to the magnets with the 24 kA current leads that terminate at the BT current lead turret and the ECT service turret.

A full functional test of each coil will be carried out in the test station, which comprises:

- Warm check of the electrical and thermal properties and interlocks;
- Pump down of the vacuum vessel and related leak test;
- Cool down between 300 and 100 K in 20 days and between 100 and 4.5 K in 10 days with related cryogenics tests;
- Coil tests with current ramps up to 21 kA and quench test;
- Warming up.

V. Cryogenics System

The cryogenics system [3] is based on immersed centrifugal pumps to circulate two phase He flow of nominally 80 g/s through the cooling pipes of the magnet cold masses. For the thermal shields 60 K He gas is supplied. The current leads require 3 g/s liquid flow. This cryogenic system provides all the necessary functions including the cool down of the magnets from ambient to baseline temperature and flexible operational conditions.

It comprises the refrigerator cold box 1.2 kW at 4.5 K and related compressor, the pump cryostat containing two immersed centrifugal pumps in their anti-cryostats, the distribution valve box, the liquid nitrogen pre-cooling unit and related compressor, three transfer lines feeding the test benches, the instrumentation and the process controls. The equipment will be installed and commissioning will be completed by the end of the year 1999.

The pump cryostat and its instrumentation were tested and the principle of immersed centrifugal He pumps has been validated. Preliminary performance characteristics of the pump were obtained and the technical specifications were confirmed. The use of immersed pumps with its specific design gives an extra safety measure in the case of failure of the refrigerator allowing for 1 hour of autonomy. This covers twice the time required for a slow discharge of the BT coil. Commissioning of the refrigerator and related compressor was successfully accomplished. A combined test of the cryostat and

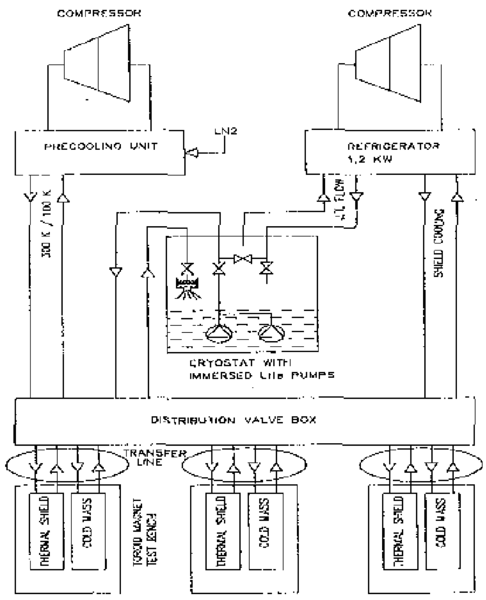

Fig. 6. Flow Scheme of the Cryogenic System.

refrigerator to verify the functioning of the different components, namely the flow meter, the phase separator, the quality meter was carried out. In this context the development of a new quality meter, the void fraction meter and the construction and testing of a Venturi flow meter at 4.5 K was carried out. Moreover the common control system was tested through simulation of the coil thermal losses by heaters, the safety pressure control valve for the failure mode and the liquid He consumption for the magnet discharge scenario were tested. The simplified flow scheme of the cryogenics system is shown in Fig. 6.

VI. Power Supply System

A 6V/24kA power supply of the switch mode type to charge the magnets and a 45V/450A auxiliary power supply to finally warm up the coils are required for the test. The implementation of the power supply in switch mode has the main advantage of reducing the volume of the power supply and introducing modularity and redundancy. The system comprises a power converter and DCCTs, circuit breaker, dump resistor and diodes unit, bus bars and flexible connections, current leads, coil satellites, 230/400 VAC main distribution and control room for the data acquisition and analysis. For safety reasons a 230 VAC uninterruptible power supplies are used to supply essential parts of the power system which must guarantee the safety of the magnet. Installation and commissioning of all these components are completed by the beginning of 2000.

VII. Magnet Control and Safety Systems

For testing of the coils, a prototype of the control and safety interlock system of the final system in the underground cavern will be used. For reasons of uniformity, ease of operation and maintenance, the systems are built from similar modules in a layered architecture. The main functions of MSS are the magnet protection in a stand-alone mode with fast and slow dump request treatment and the personnel safety. Auxiliary functions are the data provision for diagnostics and the alarm system. Uninterruptible power supplies are required for powering the system so as to guarantee the functionality of MSS during at least the time of a slow discharge. Dual redundancy is implemented. The main functions of MCS are the process control for ensuring the operating sequences of the magnets and the monitoring and control of all the functional parameters.

The system provides control over the following:

- Magnet parameters;
- Internal and proximity cryogenics;
- Power supply and electrical system, bus bars and current leads;
- Vacuum system.

VIII. Conclusions

A preliminary test of B00 model coil, which represents the different conductors of the ATLAS magnet system, will verify the superconductor performance and will commission the test station. Thereafter the B0 model coil will be tested and the main functional aspects of the toroid construction will be verified. Moreover testing of the ECT and the CS is a crucial step to demonstrate the reliability of such a complex magnet system, which for its exceptional size and technological processes represents a challenge in both physics and engineering research and development.

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