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Commissioning of the ATLAS Central Solenoid Cryogenics

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The Central Solenoid (CS) is part of the superconducting magnet system of the ATLAS experiment under construction for the CERN Large Hadron Collider. It provides an axial magnetic field of 2 T at 7600 A in a 2.5 m diameter bore with length 5.3 m and is indirectly cooled with two-phase helium flowing in pipes welded to the coil support cylinder. The solenoid shares the cryostat with the liquid argon Barrel Calorimeter detector, a particularity which couple the two cryogenic systems. After several years of stepwise construction and extensive on surface test and acceptance campaigns, the integration work in the 90 m deep underground ATLAS cavern is completed. The solenoid was cooled to baseline temperatures conditions with the two helium refrigerators in their final configuration. The cryogenic system of the solenoid magnet was commissioned together with the control system and the process logics. All operation and emergency modes were tested and forced flow and passive thermo-siphon cooling successfully validated.

INTRODUCTION

At CERN the 27 km circumference Large Hadron Collider (LHC) is under construction. ATLAS is one of four large particle experiments to exploit the capabilities of colliding beams after commissioning in 2007. The detector is installed underground in a 54000 m^3 cavern and uses a complex array of superconducting toroid magnets and a Central Solenoid (CS) for momentum analysis of charged particles produced in the 14 TeV proton-proton collisions. The CS and the proximity cryogenic system (PCS) for its cooling have been designed by KEK in collaboration with CERN and fabricated by Toshiba, Japan [1]. Several on surface tests of components have been made both in Japan and, after delivery also at CERN [2]. After integration of the solenoid in the common cryostat of the liquid argon barrel calorimeter a surface test of the completed system was conducted at CERN [3]. Subsequently the components were dismounted and installed at the ATLAS underground detector cavern. This paper briefly describes the cryogenic system for the cooling of the magnets and the proximity cryogenics for the solenoid and summarizes the results of the commissioning in its final configuration.

CRYOGENIC SYSTEM FOR THE ATLAS MAGNETS

ATLAS uses two different types of superconducting magnets systems; the toroidal magnets comprising the Barrel (BT) and the two identical End-Caps (ECT's) forming an envelope of 20 m diameter and 26 m length and, a comparatively small CS of 2.5 m diameter and 5.3 m length. Due to the different cooling schemes and cold mass – toroids 660 tons, 5.5 tons the solenoid- two different and independent PCSs were required which have been designed, constructed and installed in the cavern at proximity to the detector to supply the magnets with cryogen from a common distribution valve box. A transfer line makes the link to the two refrigerators, the Shield Refrigerator (SR) and the Main Refrigerator (MR), installed at 80 m distance in a protected radiation free technical side cavern [4, 5]. The SR has two functions; the cool down from ambient to approx. 80 K of the cold mass and thermal shields and the dedicated cooling of the thermal shields at 40 to 80 K during permanent baseline operation. The MR is a 6 kW @ 4.5 K machine to supply supercritical helium to the respective magnet PCS for their two-phase cooling. Fig. 1 illustrates the simplified flow scheme of the overall cryogenic system.

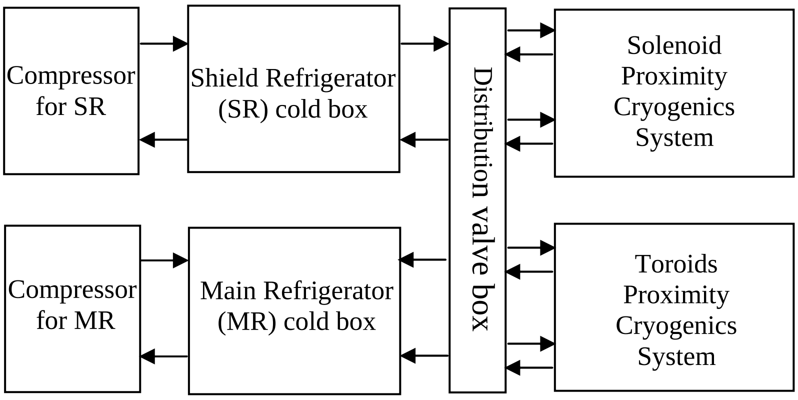

Figure 1 Simplified flow scheme of the cryogenic system (two refrigerators and distribution valve box to the two PCS for the toroid magnets and solenoid, respectively)

SOLENOID MAGNET AND PROXIMITY CRYOGENICS DESIGN

The magnet is designed for high "transparency" of particles with thin coil and support cylinder [1]. Placed at short distance in front of the barrel liquid argon detector it shares the same cryostat vessel and provides an axial field of 2 T at 7.6 kA for the inner tracker. The 44 m^3 volume of liquid argon is cooled to 87 K and its vessel serves as the external thermal shield to the solenoid cold mass while at the inner radius an active 40-80 K shield is installed. The solenoid cold mass is indirectly cooled with a two-phase flow helium in inclined serpentine shaped cooling pipes welded to the outer support

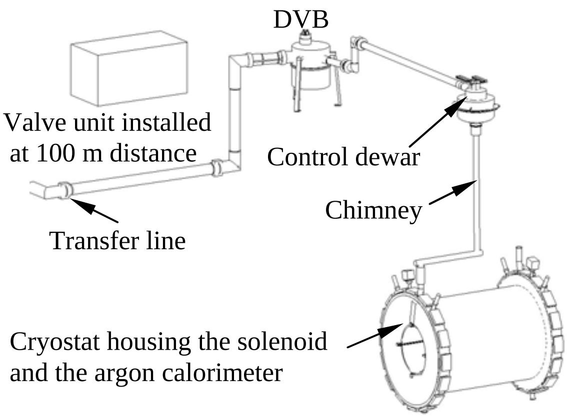

Figure 2 A 3D integration drawing in the cavern

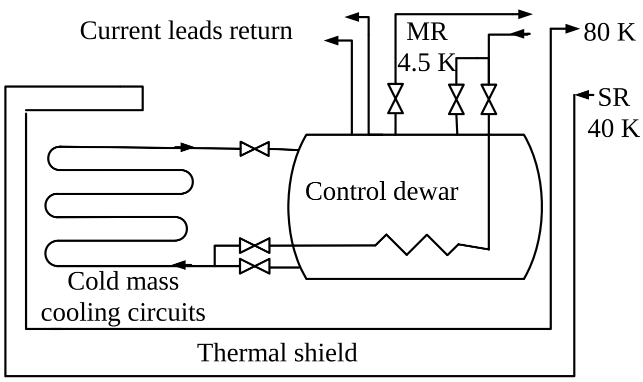

Figure 3 Flow scheme of the solenoid proximity cryogenics (simplified)

cylinder. The PCS has two major components: the control dewar and the valve unit. The control dewar is placed on top of the ATLAS detector at a distance of 13 m with respect to the central axis. Cryogenic connections between the solenoid and the control dewar is done with a chimney which houses also the superconducting bus. The valve unit, as second major component, houses the warm control valves, instrumentation and the electronic equipment. As proven by radiation experiments, the expected ionisation and hadron radiation in the detector cavern can severely harm the electronic equipment. It has, hence, been installed at a protected area at more than 100 m distance in the technical side cavern requiring important instrumentation modifications. Figure 2 shows a 3D integration drawing in the cavern. Figure 3 shows the flow scheme of the proximity cryogenics.

COMMISSIONING OF THE CENTRAL SOLENOID CRYOGENIC SYSTEM

Cool down and baseline operation

Prior to the solenoid the liquid argon barrel calorimeter was cooled from ambient to 87 K which is a precondition for the functioning of the solenoid as the calorimeter vessel housed in the same cryostat serves as an external thermal shield. The internal thermal shield requires active cooling. For the initial cool down the SR refrigerator was used only connecting the cold mass and the active thermal shield of the solenoid PCS in series. Fig. 4 shows the temperature variation of the cold gas inlet and return flow and the max./min. temperatures on the cold mass plotted versus time. For the cool down from ambient to 75 K the temperature difference did not exceed the 40 K limit with a cooling speed below 3.5 K/h. At 75 K the circuits on the PCS were split and the SR used to cool the active thermal shield while the MR was connected to the cold mass for its final cool down to 4.5 K. When the magnet reached 4.5 K the phase separator in the control dewar was filled by the excess liquid return flow.

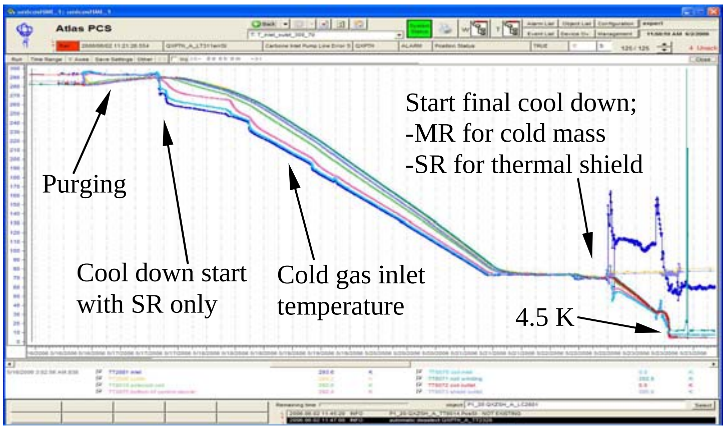

Figure 4 Cool down curve

At baseline operation the supercritical helium flow from the refrigerator is sub-cooled in the bath heat exchanger and then expanded to provide continuous liquid helium to the magnet cooling circuits. The excess liquid of the two-phase flow returning from the magnet is vaporized by a heater to control the liquid level.

Emergency operation tests

After completion of the cool down an extensive test of all safety systems and interlocks was performed. This included a full response test of the cryogenics and control in case of a magnet quench or a fast dump of the current. The cryogenic process control system, designed for operating in conjunction with the magnet controls and magnet safety systems (MCS, MSS), must be able to handle all emergency situations and failures and shut down the magnet safely. As major system failures have been identified:

a) Quench (or fast dump) of the magnet b) MR stop (4.5 K supply to magnet PCS)
c) SR stop (cooling of thermal shields) d) PLC or services failures

a) Upon quench or fast dump the cryogenic control system goes into quench mode. The PCS is isolated from the MR refrigerator and the high pressure gas from the magnet discharged via the quench lines.

b) MR stop. The direct refrigerator flow supply to cool the magnet is interrupted. Thermo-syphon mode is initiated as described in the following chapter. Signal to initiate slow discharge of the magnet.
c) SR stop. Signal is given to initiate slow discharge of the magnet. MR continuous normal operation.
d) The systems engineering provides for intrinsic safety, i.e. even in the unlikely event of a PLC or services failure (electricity backed by UPS, compressed air by high pressure bottles) the system will shut down to fail safe position which is the thermo-syphon mode accompanied with magnet discharge.

Thermo-syphon operation

The thermo-syphon operation mode is of great importance to allow safe shut down of the magnet without provoking quench situations. For this mode the MR refrigerator is isolated and the 250 l of stored liquid helium directly supplied for the gravity assisted autonomous cooling of the magnet and chimney. The two-phase return is separated in the control dewar. To avoid any perturbations the pressure is controlled at exactly the same level as during normal supply with the MR. These tests were the first under final configuration and, conducted successfully proving the validity of the design made. Time span for slow dump is less than 20 minutes while the cooling autonomy extends to 30 minutes.

Instrumentation

The large distance between the valve unit and control dewar required modification of instrumentation for the pressure measurement an innovative approach was adopted by applying long capillaries to bridge more than 100 m from the pressure pick-up to the sensors. This principle has previously been verified with a laboratory set-up and partially during the last surface tests [3]. However, this is the first time in the final underground configuration with a complex routing of the capillaries. As result we could observe that all pressure measurements -even in the range of few mbar for level metering- were reliable, hence, proving the validity of the technology adopted.

Process control

Cool down, baseline operation and all emergency and recovery operation modes are fully automated, integrated into the standard for the control system UNICOS [6]. The SCADA system has been produced to cope with the needs of the operation team; a local control room has been installed from which the commissioning has been conducted, as well as a CERN Common Control room (CCC) for future use.

Magnet tests

The magnet control and safety system was fully commissioned. For technical reasons the ramp current during this campaign was limited to 1 kA. Excitation of the solenoid and current dumps were performed with speeds up to 7 A/s. The available cooling capacity proofed to be sufficient to absorb all eddy current losses without significant heating of the coil. The thermal budget of solenoid and chimney were measured to 18 W.

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