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FINAL TESTING OF THE ATLAS CENTRAL SOLENOID BEFORE INSTALLATION

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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. It 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 solenoid is housed in the cryostat of the liquid argon barrel calorimeter. This paper summarises the tests of the proximity cryogenics and the solenoid magnet made in Japan and at CERN.

MAGNET AND CRYOGENICS DESIGN

The CS has 5.3 m length with an inner diameter of 2.5 m and provides 2 T at 7.6 kA for the inner tracker. The 5.5 ton magnet is designed for high “transparency” of particles with thin coil and support cylinder (1). In its final arrangement it is placed at short distance in front of the barrel liquid argon detector sharing the same cryostat vessel (Fig. 1). The 44 m³ volume of liquid argon is cooled to 87 K and its vessel serves as 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 cylinder. The proximity cryogenic system has two major components: the control dewar and the valve unit. In the final underground installation the control dewar will be placed on top of the ATLAS detector on a support structure at a distance of 13 m with respect to the central axis. Cryogenic connections between

the solenoid and the dewar is done with a chimney which houses also the superconducting bus. In normal operation mode the helium refrigerator (2) provides a supercritical helium flow. After being sub-cooled in the 250 l control dewar it is expanded for two-phase cooling of the cold mass. In case of emergency (refrigerator failure) this stored quantity is directly supplied to the magnet in gravity assisted thermo-syphon cooling mode providing autonomy for slow discharge of the magnet. 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 to the electronic equipment. It has, hence, been decided to install this unit at a protected area at 150 m distance in the technical side cavern, thus requiring adaptation of instrumentation.

Figure 1 Final arrangement of the proximity cryogenic system for the central solenoid and the common liquid argon barrel cryostat. The valve unit will be installed at 150 m distance in a side cavern.

TESTS IN JAPAN

Proximity Cryogenics

For the first cryogenic test of the proximity cryogenic system at Toshiba works the chimney was lowered into a vertical pit and connected to the control dewar at its top to simulate the vertical arrangement corresponding to the final installation (see fig. 1). At the bottom of the chimney the cooling pipes and the superconducting bus were short-circuited and heaters placed for load simulation. Being the only location permitting such tests prior to final underground installation at the ATLAS cavern, particular attention to the emergency thermo-syphon cooling operation mode was given, which was confirmed.

Magnet Test

A full test was conducted with the magnet in a temporary cryostat and the chimney mounted horizontally. The temporary control system used was based on a Yokogawa Astnax PLC system with programmed operation modes. At 4.5 K operation, pressurised mobile dewars supplied the magnets cooling circuits. The return gas flow was used after phase separation in the control dewar to cool the inner and outer thermal shields connected in series. Performance tests were conducted and quenches induced by heaters. Ultimately 8.4 kA was reached without quench (nominal 7.6 kA). At 4.5 K the magnet static heat load measured was 11 W. Eddy current losses amount to 25 W at nominal ramp rate.

PRELIMINARY TESTS AT CERN

Re-commissioning

After shipment to CERN the proximity cryogenic system was installed in a surface test hall for re-commissioning and a first test series. The horizontally positioned chimney was equipped with a cap containing the shorts for the cooling lines and superconducting bus and, local heaters. Already at an early stage of the new LHC UNICOS standardisation project for industrial control systems, a Schneider Quantum PLC was applied for process control with the adapted functional logics. The current was ramped to 9 kA and quenches simulated for testing the magnet control (MCS) and magnet safety systems

(MSS). Thermal load simulations showed an effective refrigeration capacity of 70 W at the terminus of the chimney which is considered to be sufficient for the final cooling of the magnet when compared to the actual thermal budget of 36 W as measured in Japan (magnet static load 11 W, dynamic load 25 W)

Instrumentation adaptation and testing

To protect the sensitive equipment of the valve unit from harmful radiation in the detector cavern its installation at 150 m distance in a non-radiation technical side cavern is needed. In order to limit modifications of the existing instrumentation, an investigation was done to verify if 150 m long capillaries could be used to bridge the measurement pick-up in the control dewar to distant pressure transducers. The test program consisted of signal response experiments in a laboratory set-up and a field test after implementation of the complete proximity cryogenics. To quantify the pressure signal delay, transducers were connected to 150 m long transmission capillaries of different diameter and the signal response compared with a reference. The results indicated that the response time is almost independent from the amplitude of the reference signal, both for absolute and relative pressure transducers, even at very small pressure differences of a few mbars. Figure 2 shows representatively the response time of a relative pressure transducer for three different diameter capillaries at a reference pressure rise of 10 mbar. The fastest response is obtained with the largest tube of 8 mm diameter exhibiting 10 seconds delay. For the application this response time was considered to be sufficient and equivalent capillaries were installed in the proximity cryogenic system for verification of the overall process. The positive results proved the feasibility of this solution which was adopted.

Figure 2 Pressure transmission in 150 long capillaries

Figure 3 Integration of the solenoid in the cryostat

FINAL TEST PREPARATION

After the installation of the two calorimeter detector wheels in the liquid argon barrel cryostat the solenoid was integrated and the chimney connected to the top of the cryostat. Figure 3 shows a photograph of the solenoid and the common cryostat during the integration phase and figure 4 a principle test lay-out. The configuration of the cryogenic controls corresponds to the final UNICOS standard with PVSS supervision. Signal and interlocks are exchanged between the solenoid, the liquid argon system and the MCS, which also use the UNICOS standard. Interlocks from MSS are directly hardwired to the solenoid cryogenic system.

The cooling of the 110 t detector cold mass has started on April 20 at rate of about 0.3 K/h. At detector temperatures close to the final 87 K the solenoid will be cooled down to 4.5 K. All the different operational scenarios foreseen for the final installation will be applied and validated. After filling of the calorimeter with 44 m³ of liquid argon, the final combined surface testing of the two cryogenic systems will start. Static and dynamic load measurements of the solenoid will be made and the magnet operated with the final MCS and MSS systems. A series of fast discharges and heater initiated quenches will be made. The overall schedule being limited, a fast re-cooling is required after each magnet temperature excursion (up to 70 K). For this purpose an extension to the actual cooling system has been made in using a 10000 liter mobile helium dewar which is connected to the control dewar phase separator of the proximity cryogenics (Fig. 5). For re-cooling liquid helium will be withdrawn from the dewar and

injected in the 250 l phase separator to cool the refrigerator J.T. flow going to the magnet and the vaporized helium from the phase separator is taken back by the cold box. By using this facility the overall system is “boosted” and the re-cooling of the magnet to operation temperatures shortened down to a few hours. After the completion of the testing of the calorimeter, the cryostat will be heated up to ambient temperatures and the systems will be ready for final underground installation

Figure 4 Principle experimental set-up

Figure 5 Simplified flow scheme

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