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ATLAS silicon microstrip tracker operation

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ABSTRACT

The Semi-Conductor Tracker (SCT) has been built and installed into the ATLAS detector at the Large Hadron Collider (LHC) in CERN. Together with the Pixel and Transition Radiation Tube (TRT) detectors it will provide precise tracking and vertexing information for the ATLAS Physics program. In this paper we report on the status, operational experience, and performance of the SCT in the run up to the start of the LHC.

1. Introduction

There are three charged particle tracking detectors in the ATLAS detector, as shown in Fig. 1. The innermost detector is the pixel detector for precise vertexing. The SCT is located outside of the pixel detector and is mainly for tracking and to improve the primary and secondary vertex finding. The outermost part is TRT for continuous tracking to large radius.

The SCT consists of a central barrel and two endcaps. The barrel and endcaps were installed into ATLAS cryostat in 2006, and 2007, respectively. The installation was followed by a period of commissioning including: the cooling, electrical and optical connectivity tests, calibrations (optical and electrical), Detector Control System and other system check out tests. After that, cosmic rays were used to tune the operation of the detector to be ready for the delivery of the first beam by the LHC.

The LHC delivered first single beam in September 2008. The SCT succeeded in observing the first beam splash events produced by allowing a single pilot bunch to impact on collimators upstream of the experiment. The problems of the LHC following the accident on September 19th have meant that we have been waiting around a year for the restart of the LHC. We expect the LHC resuming operation in November 2009.

The LHC's design value of luminosity is $10^{34}\,cm^2\,s^{-1}$. The bunch spacing is 25 ns. From these two parameters it is understood that the SCT is required to be radiation hard, and have low occupancy in spite of the short bunch spacing and hence short integrating and/or shaping time at the front-end. In this paper, we describe the design of SCT [1,2], the current status and the operational experience, and the performance recorded to date.

2. Design

There are four barrel layers, and nine disks per each endcap. The barrel covers $|\eta|$ less than 1.1–1.4 depending on the location, and the endcap covers $|\eta|$ greater than 1.1–1.4. The barrel consists of 2112 modules, and the endcap consists of 988 modules per endcap, a total of 4,088 modules.

Each barrel module consists of four approximately square ($6 \times 6\,cm^2$) p-on-n single sided silicon sensors; two sensors on each side are electrically connected to give 768 strips of approximately $12\,cm^2$ long, mounted on the thermal and mechanical support. The strip pitch is $80\,\mu m$. Another pair of sensors is glued back-to-back to the first pair again on the support with the stereo angle of 40 mrad, giving a two dimensional determination of hit position. The six ABCD3TA [3] readout chips are mounted on a multi-layer Cu-polyimide flex circuit for each side. There are 12 readout chips or 1536 strips per module, and hence approximately 3.2 M readout channels for the barrel.

The endcap module has similar structure to the barrel. The difference is a wedge shape of the sensor to build up the disk shape, hence there are different sizes of sensor or module depending on the location, i.e. whether it sits on inner, middle, or outer part of the disk. The strip pitch varies from 57 to $94\,\mu m$. Again there are 12 readout chips per module, resulting in approximately 1.5 M readout channels for each endcap.

The grand total of the number of readout strips is 6.3 M (4088 modules $\times$ 12 chips $\times$ 128 channels per chip).

In order to minimize the size of the data read out when a charged particle crosses the tracking detectors, the ABCD3TA front end chip is designed to send only the channel address for the strips that are above a pre-defined (programmable) threshold.

The total heat load per module is 5.6 W before irradiation. To sustain the radiation damage up to 2×10^{14} neutron equivalence per cm^2 at the innermost layer, the sensors are cooled down to $-7\,^{\circ}C$ by a two-phase cooling system using C_3F_8 as a coolant.

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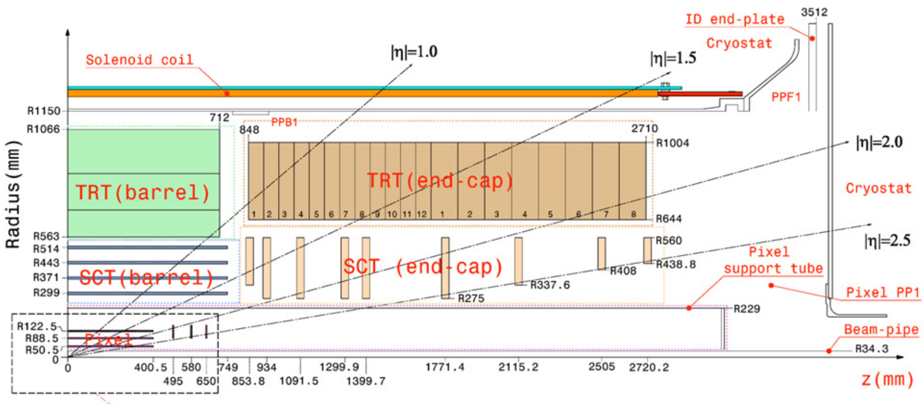

Fig. 1. The plane view of the charged particle tracking system at the ATLAS.

At the same time, the sensor can sustain up to 480 V bias voltage to be fully depleted after the total flux we expect to see over the 10 year lifetime of the SCT.

The communication between the modules and off-detector electronics is established by optical links [4]. The Back Of Crate (BOC) card plays the role of the interface between the Read Out Driver (ROD) module and the optical links on the modules. For each module, clock and command signals are sent from the BOC by a single optical fibre, while the data from the module are sent back to BOC by a pair of fibres one corresponding to each side of the module. The clock and command signal is transmitted to the module by the TX plug-in, and the data on the module is received by the RX.

As the detector is not accessible once the whole ATLAS detector is integrated, a readout redundancy scheme is important. On the module, the six readout chips are daisy-chained, and read out by one optical fibre, as mentioned above. In case a chip is not functional, the readout chain can be configured to bypass the malfunctioning chip. In case of broken optical fibre for data readout, the data can be routed to an optical link for the other side on the module. Finally, there is a spare route for clock and command signals. In 2008 there were a series of failures of the off-detector TX transmitters due to ESD damage in construction. Extensive use was made of the redundancy scheme while waiting for the manufacture and installation of the replacement units. The units were replaced in July and August 2009.

3. Status and operational experience

The first beams were injected into the LHC on September 10th 2008. The beams were injected separately in both directions (clockwise and counter-clockwise) without ramping. At pre-defined times the single beam was allowed to hit the collimator and created a beam splash consisting of thousands of particles entering the ATLAS detector. The endcap observed many space hit points, although the bias voltage was set to 20 V which is lower than the nominal value of 150 V for reasons of safety. This indicates that the SCT was integrated to the ATLAS DAQ in proper timing, and was ready for beam in time.

Unfortunately the failure of the bus-bars connecting two superconducting magnets and the subsequent collateral damage and helium leak has stopped the LHC program for more than one year. Using the long LHC down time, the SCT collaboration continued to systematically check and improve all of its control systems. Table 1 presents the fraction of non-functional channels relative to the total 6.3 M readout channels. As can be seen, more than 99% of the channels are active. There is one cooling loop which is not functional because of the leak inside the detector. The modules mounted on this loop are not powered on, although the modules themselves are functional. The two modules are not functional because there is an open circuit in bias in one module and short to ground on the control line in the other. The 10 chips cannot be read out, because a master chip in each link in the barrel cannot be read out with the redundancy scheme where one side of the optical fibre is broken, i.e. this is attributed to 10 bad optical links, not the problem of chips themselves. The remaining problem in strips is mainly high noise. However, the number of bad strips per module is mostly less than 15 which meets our design specification.

Table 1
Fraction of non-functional components.

Disabled components	Not expected to be resolved (%)	Yet unresolved
Cooling loop	0.32 (one loop)	0
Module	0.05 (two modules)	0.42% (17 modules)
Chip	0.02 (10 chips)	0.03% (16 chips)
Strip	0.16 (10,151 strips)	0
Total	0.55	0.35%

In terms of operational experience, there were two major issues. The first one was mentioned above and relates to the TX plug-in for the optical links. There seems to have been ESD damage in production and the SCT observed the number of non-functional TX plug-in gradually increase. As of writing of this paper, all the damaged TX plug-in have been replaced.

The second one was related to the cooling. The failure of three out of six compressors on May 1st 2008 was a severe set-back. The three compressors were repaired within three months and most of the pipe-work in the system was replaced or cleaned. Additional problems of excessive vibrations affecting all six compressors meant that all of the compressors were retrofitted by the vendor in the winter of 2008–2009.

The only remaining issue is related to the failure of some large area heaters pads between the SCT and the TRT. These pads are designed to maintain the thermal neutrality between the SCT and TRT. Without these pads the cold SCT would cool down the TRT below its design operational temperature. Therefore, the outer part of the SCT Barrel operates the coolant at $-10\,^{\circ}$C instead of $-25\,^{\circ}$C. But this problem affects only the outer layer of the Barrel. We do not expect a significant impact on the lifetime, because the innermost layer, which is expected to have the severest radiation damage, can still run cold.