10th ICALEPCS Int. Conf. on Accelerator & Large Expt. Physics Control Systems. Geneva, 10 - 14 Oct 2005, TH3B.2-3O (2005)

A DISCRETE EVENT SYSTEM THE CMS TRACKER INTERLOCKS

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ABSTRACT

The paper describes the individual processes that combine to form to form the Safety, Controls and Monitoring tasks needed for the proper operation of the CMS Silicon Strip Tracker at the required performance level. None of these processes includes any "data-acquisition" related activity; their role is first and foremost to ensure the safety of the detector itself and of its operators, and to keep it as close to full operability for its intended lifetime of 10 operating years at LHC. The hardware and software used for the control and monitoring systems are described, together with a short history and the current status of the project.

THE CMS TRACKER CONTROL AND INTERLOCK SYSTEM COMPONENTS

Short overview of the CMS Tracker.

With an active area of 206 m^2 divided in 16,000 modules, the CMS Silicon Strip Tracker [1] is the largest such detector ever built. It is designed to provide excellent resolution and two-track separation for charged particle tracks coming from very high energy pp interactions.

A schematic of the CMS Tracker can be seen in Fig. 1, where the different colouring scheme outlines the different subdetectors: in purple the very inner Pixel Tracker, which are not object of this paper; in red the Inner Barrel and Inner Disks; in blue-green the Outer Barrel; and in blue one of the two End Caps. Both the Inner Barrel/Disks and the Outer Barrel are geometrically and functionally split into two parts around the plane perpendicular to the beam in the interaction point.

The control systems of the Tracker have had to evolve in parallel with the Tracker itself. An experimental device of such size is by no means a standard design that can be fully realized by using existing solutions and components. Controls and monitoring of a detector are a very important issue that has to do with its ability to perform efficiently. They have to be thought of in parallel to the evolution of the design of the detector. Unfortunately, for diverse reasons, the case is not always such. Processes designed in the initial designed detector phase are adjusted to new requirements rather than be re-engineered. There is usually a hybrid situation in which the controls project has to inherit already implemented designs and implement others. The CMS Silicon Tracker has been no exception to this.

Since the two halves of the Inner Barrel/Disks and the two End Caps will be assembled in the home labs separately, and delivered to CERN for the final integration at different times, the control system had to be designed around this granularity; due to the large number of channels involved, it was also expedient to split the control system for the Outer Barrel, thus leading to what effectively can be seen as six largely independent, very loosely coupled control (and mostly safety) systems.

The silicon strip Tracker counts overall more than 10,000,000 linear diodes, reverse biased, each read by a charge-sensitive preamplifier matched to the strip characteristics of the front-end readout chips. The readout chips contain 128 channels of pre-amplifiers and analogue memory, together with the circuitry needed to receive triggers, mark columns of the analogue memory as "in use" and serialize the 128 samples corresponding to the trigger time on a single differential output channel at a frequency of 40 Msamples/s.

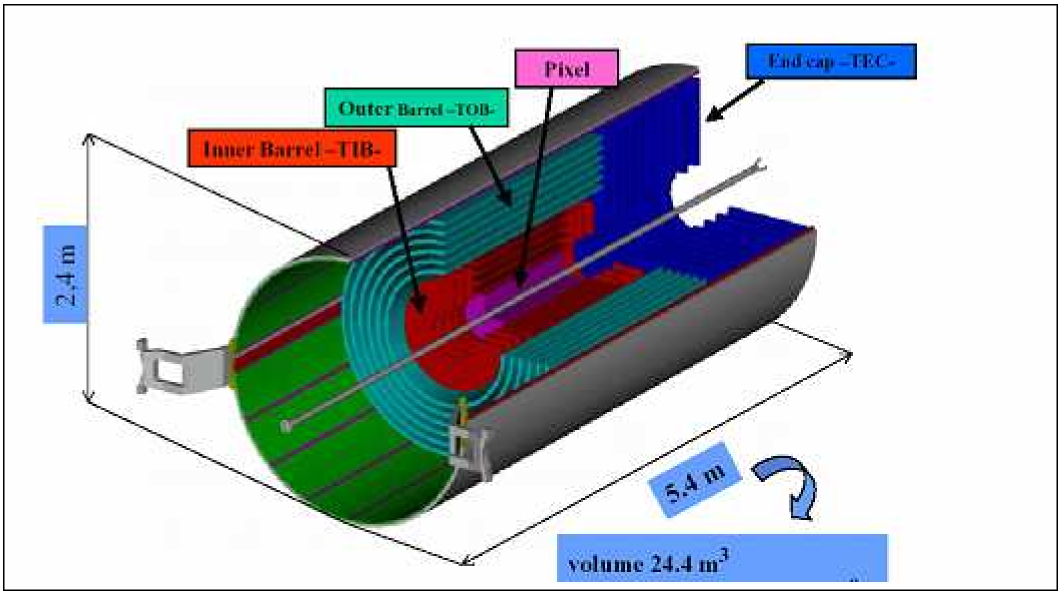

Figure 1: The CMS Tracker-Pixel, Inner and Outer Barrels and End cap section

Two chips, multiplexed in the time domain, share an electrical to optical converter, for better noise rejection. The optical signals, carried to the surface by long ribbons of optical fibers[2], are then converted back to electrical and digitized in the Counting Room. The programmable front-end chips communicate with the external world, for the purpose of downloading and uploading parameters, over I2C buses. A dedicated concentrator ASIC, the CCU, handles 32 such buses in parallel, and in turn communicates with a VME board, the FEC9U, over a token-ring network which runs partially on optical fibers.

The Silicon Strip Tracker power supply system has been designed with the contrasting requirements of a fine granularity and an affordable cost. In order to reach a reasonable compromise, two types of specialized power supply channels have been developed: one is meant for powering sensor modules, and provides Low Voltage (2.5 and 1.25 V) at relatively high currents, together with two High Voltage lines capable of providing up to 10 mA at 600 V. In order to power the Tracker, a total of approximately 2,000 channels, housed in 200 remotely controlled crates located on the balconies surrounding the CMS detector, inside the experimental cavern, will be needed. Due to the need to minimize the cable cross-sections inside the detector volume, the total power dissipated in the internal cables is equivalent to that dissipated by the Tracker electronics and sensors, and depending on the final choices for the cables and also somewhat on the front-end operating point the total dissipation inside the CMS volume due to the Tracker will amount to 100 kW or more, approximately half of which in the cables.

The mechanical structure housing the Tracker partially serves as its cooling structure as the Tracker shall be operated at -10^0 C. This temperature was the conclusion derived from an intensive R&D program aimed to maximizing the Tracker lifetime given the expected irradiation. This temperature has the combined advantages of minimizing reverse annealing, reducing by a large factor the dark currents and countering the possible occurrence of thermal runoff which would have potentially catastrophic consequences. Operating the Tracker at this temperature implies that a redundant cooling system has to be added to its support machinery. The coolant, according to the

CMS design, shall be distributed throughout the detector via 216 cooling segments and is going to be in continuous circulation throughout the detector lifetime.

An active thermal interface, called "Thermal Screen", insulates thermally the Tracker from the surrounding detector, the ECAL (Electromagnetic Calorimeter). This allows the two detectors to be operated at rather different temperatures (the ECAL nominally runs at $+17^0$ C, versus the -20^0 C of the Tracker), and the Thermal Screen can also double up as an extra "cooling system" for the Tracker: In case of a failure of the Tracker cooling plant, there are emergency cooling units that will keep the inner side of the Thermal Screen at the desired temperature (provided that the Tracker has been powered off, of course). Apart from the detector-related issues, the stability of the temperature at the interface between the two detectors, and its uniformity, help in reducing the risk of thermally-induced deformations in the Tracker support tube. The Thermal Screen is indicated as the purple-green shell surrounding the Tracker in Fig. 1.

Factors that affect the lifetime and performance of the Tracker.

After this short description of the Tracker, we find ourselves in a better position for defining the factors that can affect its lifetime and performance.

- Temperature extremes

Temperatures outside the specified operating range can occur in case of problems with the cooling plants, or with individual cooling segments. Temperatures below the allowable thresholds can result in permanent mechanical deformations of the support structures, and possibly in the fracture of solder joints in the coolant-carrying pipes, resulting in coolant leaks. On the other hand, over-temperatures, in particular after the Tracker has sustained a significant irradiation, can give rise to "reverse annealing" phenomena, leading to increased dark currents, increased bias voltages and reduced charge collection efficiency in the Silicon strip sensors, which will eventually result in the impossibility to deplete the detectors and operate the Tracker. Additionally, should "thermal runoff" occur (increasing temperature causes the dark current and therefore the dissipated power to grow; this in turn produces a further increase in temperature) the possibility of more instantly fatal damage is real. While some of the front-end chips can sustain permanent damage if operated above 40^0 C, most of the front-end electronics components are sensitive to the operating temperature, requiring changes in the downloaded parameters should the temperature vary too much. This does not have permanent effects on the Tracker, but can reduce its overall operating efficiency, since during the parameter download the Tracker cannot be considered functional.

- Power failures

The Power Supply system of the Tracker is rather complicated, and the power-up must follow a very well defined sequence, ensuring that all hardware and software needed for another step is fully operational. Since power cuts are possible, and even frequent depending on the season and weather, the Tracker Safety and Control system must ensure that recovery from a power cut happens along the correct sequence, and disable the Power Supply system unless the supervisory control application signals that all is under control and conditions have been established that allow the proper power-up of the Tracker.

- Irradiation damage

According to predictions[1], during its expected lifetime, the Tracker shall face the consequences of the crossing of 10^{12} to 10^{14} charged, minimum ionizing particle (mip) equivalent, particles/cm^2 and 10^{13} to 10^{14} neutrons/cm^2. The total irradiation levels shall vary between 10 and 65 kGy. The damage of the Tracker due to this irradiation is expected to be partially counter played by the low temperature. However, degradation will happen.

- Humidity and condensation

As already seen, the CMS Tracker will be operated essentially constantly at temperatures well below 0^0 C. Even though after integration it will be kept most of the time in a dry atmosphere, it will unavoidably be exposed to "standard air" during transportation, during installation inside CMS and during any repair access (since operators tend to malfunction at cold temperatures). Most of the Trackers mechanical support structures are in carbon fiber, which is hygroscopic, so the risk of water and ice forming either inside the mechanics or on the fragile electronics modules cannot be simply waved off. For a proper cool-down without risks, several "steps" will have to be foreseen: starting at 20^0 C with 10% relative humidity, the dew point falls at -10^0 C, which is well within the range of temperatures available to the different parts of the Tracker. In order to have a dew point of -20^0 C, the initial relative humidity at 20^0 C should be below 5%. The cramped geometry will also slow down the removal of humidity "pockets", hence the need for a gradual alteration between cooling and drying steps.

- Experimental cavern problems

Events such as fires or flooding in the experimental cavern will be handled by a separate, dedicated safety system. However, they shall certainly endanger the Tracker. It is foreseen to receive (and provide) limited information from the cavern safety system that will be used to bring the Tracker in as safe a state as possible, compatibly to the external circumstances. Typically, this will simply mean shutting off power in an orderly manner, and preventing subsequent power-up operations until the external problems have been cleared.

THE CMS TRACKER CONTROL AND INTERLOCK SYSTEM IMPLEMENTATION

System segmentation and I/O and software architecture.

The environmental and other information needed for the realization of the interlock logic for the Tracker is collected through different paths. Critical conditions, as those have been defined in the previous chapter, may occur in different parts of the Tracker and can be, or not correlated. Those different paths are independent controllers handling specific parts of the Tracker.

The recipient of the Tracker interlock logic is strictly the Tracker powering system. The Tracker interlock system will only affect the Power Supply system directly, even though it will raise warnings and alarms for the supervisory, CMS-wide, control system. In particular, no direct control on the cooling plant will be available in hardware. Software requests to modify the overall temperature of the coolant, or to shut down the coolant circulation in a given cooling segment, are the only action that will be available. Similarly, the only interaction with the plant providing dry air will be a "Plant OK/Not OK" signal. Given these limitations on the corrective actions available in case of critical conditions, the best strategy left is to strive to keep as much as possible of the Tracker operational, while shutting down local partitions affected by the problem. The assignments of Tracker subsets to power supply channels and to coolant distribution pipes has been studied, so that there is perfect overlap of power supply channels with cooling groups (and thus, no power supply channel spans over modules served by different cooling pipes). The Tracker has been designed redundant, so a regional shutdown, as long as the affected region is not too large, should leave enough measurement points to perform track identification and reconstruction, possibly with a somewhat deteriorated resolution.

The environmental sensors used in the CMS Tracker are of three main types: Pt1000 thermometers [3], thermistors (of two different models, [3],[4]) and a specialized relative humidity sensor [5]. Identifying devices that would match the requirements was far from trivial: as already mentioned, the Tracker will be subjected to rather high radiation doses, and the space available for the sensors themselves, any extra components, connectors and wires is severely limited. Furthermore, signal conditioning and readout cannot be performed any closer than at least 100 m from the sensors themselves. The TOB and TEC use thermistors for their temperature measurements.

Approximately 5,000 thermistors of type [3] will be installed inside these subdetectors: 1,000 of these directly monitor the temperature of cooling segments, and will be used in the Interlock logic, while the others, located in less critical spots, will be read-out by an auxiliary monitoring system that has no action-taking capability (but can still send warnings and alarms to the CMS-wide supervisory system). Type [4] thermistors are much more numerous (~50,000). A small number (~200) will be connected to the interlock system. The TIB has about 300 Pt1000 wired for permanent temperature measurements. For relative humidity measurements, TIB, TOB and TEC will use the same type of sensor [5], for a total of 200 measurement points spread around the Tracker volume.

The total number of analogue channels to be monitored amounts to 1,400 analogue inputs while the total number of digital outputs needed to handle the shutdowns at the finest granularity possible is of the order of 800. This is very large for a PLC system. Fortunately, the clearly separated grouping of TOB, TIB and TEC in (3+3) allows to factorize the problem. The interlocks are split into six very loosely coupled subsystems, each with 240 analogue inputs (and a handful of digital inputs, from external devices such as the cooling and dry air plants and the Thermal Screen) plus 140 digital outputs, which brings the individual PLC setup down to manageable size. Each of the six systems fills a standard rack. The systems are already in an advanced phase (most of the hardware mounted and tested) and most of the basic software tested. The system shall be gradually deployed in laboratories testing large numbers of Tracker detectors and services and shall be accompany the Tracker in the experimental cavern with the addition of a supervisor ("TRACKER") in Fig.2. This will allow the users to familiarize with the interlock logic used and suggest required modifications.

The Tracker Interlock system has been designed with the contrasting aims of stability and flexibility. Stability is clearly needed to ensure that no unexpected "event" can cause a delay or a failure of the interlock, when needed; flexibility is mandated by the long predicted lifetime of the Tracker, with consequent variations over time of the constraints. Although it must essentially operate as a standalone "black box", bidirectional communications with the supervisory system and other systems cannot be avoided: monitoring data, warnings and alarms must be sent, and commands and data must be received. Care has been put in isolating, and keeping isolated, the data transmission and reception tasks from those handling I/O and from those running the algorithms that determine whether a warning, an alarm or corrective action are called for. The basic structure of the execution of every PLC "cycle" can be schematized in:

- transfer of all input data to a dedicated dual-ported memory bank, where they can also be recovered from the supervisory system transparently from the PLC;
- analysis of the data most recently read with the generation of a list of flags in memory but without external output signals;
- analysis of the flags: this can activate external warnings and alarms, cause internal state changes, and activate external signals;
- transfer of warnings and alarms and of all monitored flags to a dual-ported memory bank;
- transfer of commands, if any, from a dedicated, dual-ported memory bank;
- command execution and command acknowledge.

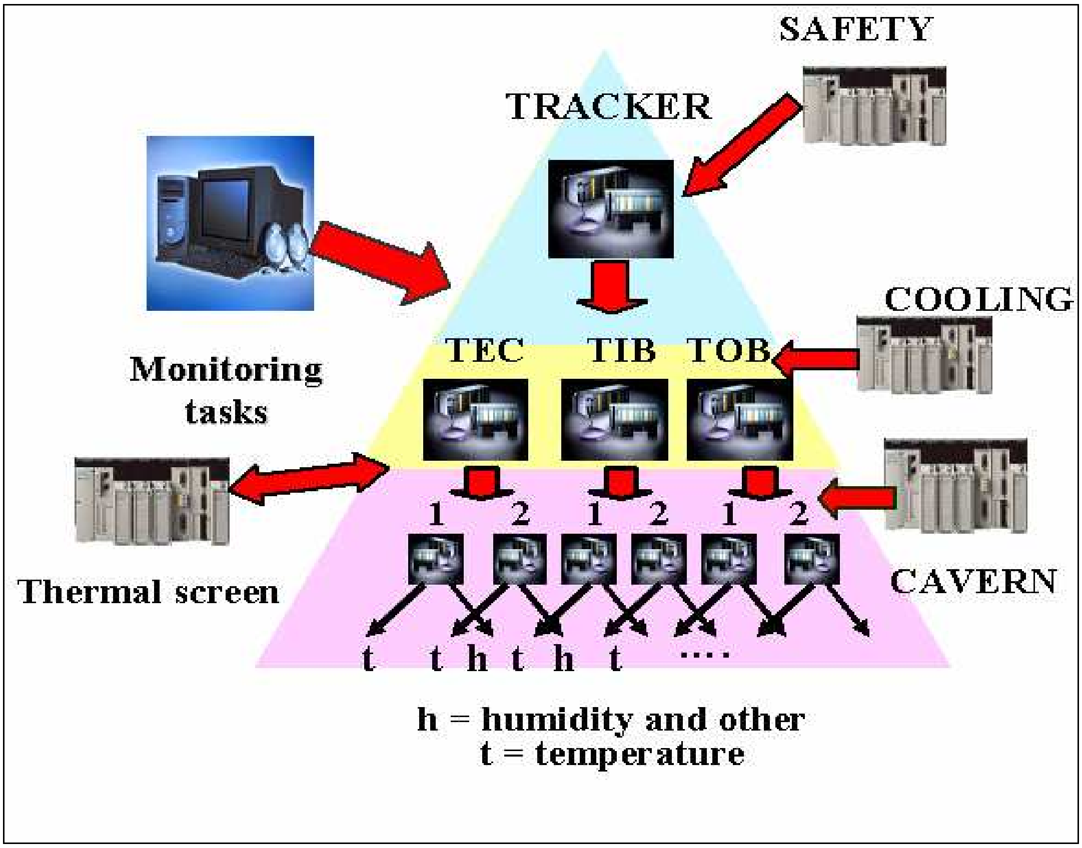

Figure 2: The different paths of information in the PLC based interlock system of the CMS Tracker

CONCLUSIONS

The CMS Tracker's interlock system is concentrating several independent and not streams of information into a PLC based system whose role is ensuring the Tracker's LHC long lifetime and performance. The partitioned system is well on its way of construction and it should all be finished by February 2006.

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