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Detector Control System for the AFP detector in ATLAS experiment at CERN

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Abstract. The ATLAS Forward Proton (AFP) detector consists of two forward detectors located at 205 m and 217 m on either side of the ATLAS experiment. The aim is to measure the momenta and angles of diffractively scattered protons. In 2016, two detector stations on one side of the ATLAS interaction point were installed and commissioned. The detector infrastructure and necessary services were installed and are supervised by the Detector Control System (DCS), which is responsible for the coherent and safe operation of the detector. A large variety of used equipment represents a considerable challenge for the AFP DCS design. Industrial Supervisory Control and Data Acquisition (SCADA) product Siemens WinCCOA, together with the CERN Joint Control Project (JCOP) framework and standard industrial and custom developed server applications and protocols are used for reading, processing, monitoring and archiving of the detector parameters. Graphical user interfaces allow for overall detector operation and visualization of the detector status. Parameters, important for the detector safety, are used for alert generation and interlock mechanisms.

1. ATLAS Forward Proton (AFP) detector

The AFP detector [1] extends the ATLAS experiment [2] physics range by tagging and measuring the trajectory of protons emitted in the very forward direction. At ~200 m from the ATLAS interaction point (IP) they are sufficiently separated from the nominal beam orbit so they can be intercepted by detectors inserted into the beam pipe aperture using the Roman Pot (RP) technology. Presently, the detector is composed of two RP stations located on each side of the IP. Figure 1 shows the two stations: the near one at 205 m from IP and the far one at 217 m from IP (Arm C), which were installed in the first stage of the installation, during the LHC 2015-2016 winter shutdown. Each station contains a single horizontal Roman Pot. The stations are virtually identical to the TOTEM RP stations,

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hence the pot mechanics and motorization are the same as in TOTEM [3], while the motor control, beam interlock system and pots secondary vacuum are copies of the ALFA [4] detector solutions.

All AFP stations contain tracking detectors. The far stations will additionally house a time-of-flight (ToF) detector, which will be used for background rejection.

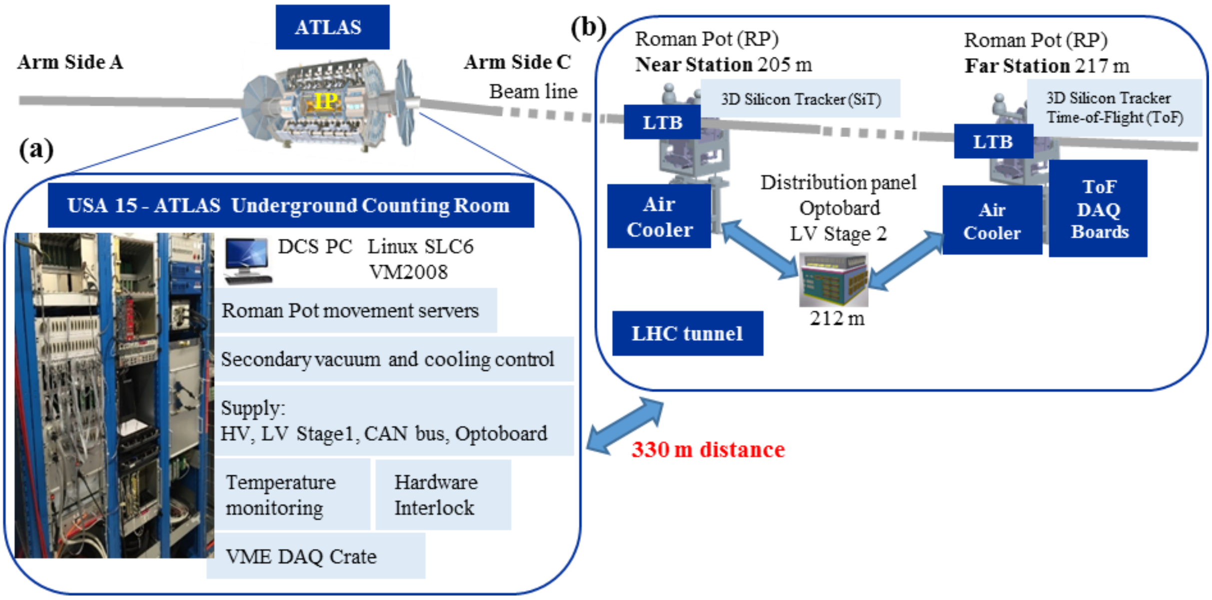

Figure 1. Placement of AFP detector and the infrastructure in the ATLAS Underground Counting Room USA15 (a) and in the LHC tunnel (b).

Tracking detectors (or trackers) are composed of four silicon pixel modules arranged along the beamline. Modules consist of 3D sensors, each sensor contains 26880 pixels of 50x250 μm^2. Front-End readout chips FE-I4B [5] bump-bonded to sensors are used for the readout. The pixel modules were developed for the ATLAS innermost pixel layer (Insertable B-Layer - IBL) [6], hence the whole infrastructure necessary for powering and operating of the detectors follows IBL solutions.

Trackers were installed in both stations of Arm C during the 2015-2016 LHC winter shutdown. During the 2016-2017 LHC winter technical stop the two stations in the second side (Arm A) will be installed together with ToF detectors in far stations in both arms.

1.1 Overview of the hardware controlled by DCS

For the safe operation with the highest performance, the detector needs several auxiliary systems with carefully monitored and controlled parameters. These systems are listed below:

- Roman Pot movement system;
- Roman Pot secondary vacuum;
- cooling of the detectors;
- distribution of low voltage, with precise setting and monitoring of all parameters;
- distribution of high voltage with precise setting and monitoring of all parameters;
- monitoring of VME bin/crate housing module needed for Data Acquisition (DAQ);
- temperature monitoring in all crucial parts of the detector;
- hardware interlock systems switching off the low or high voltage in case of the temperature exceeding the limits in crucial parts of the detector or its infrastructure.

Due to the radiation conditions in the tunnel, necessity for an easy access and maintainability during the collider activity, only the necessary hardware, proven as radiation hard, is installed in the tunnel close to the RP stations. All other equipment is located in the ATLAS Underground Counting

Room USA15, about 330 m from the stations. A large variety of the used equipment and necessity of its control over long distances is a considerable challenge for the AFP DCS design.

Figure 1 (a) shows the infrastructure, which is located in USA15. Overall DCS control and monitoring tasks are performed from USA15 by means of a computer (DCS PC) running Scientific Linux (SLC6) and Windows VM 2008. The Roman Pots movement servers, control of secondary vacuum and cooling, hardware interlock system with temperature monitoring possibility, CAN bus power, high voltage (HV) system, first stage of low voltage (LV) and Optoboard supply, as well as VME crate are installed in USA15.

Figure 1 (b) shows the apparatus installed in the tunnel. Cooling devices, called the Air Cooler boxes, are placed on the tunnel floor near each station. The Local Trigger Boards (LTB) are installed on the pots flanges. They provide the trigger and DAQ functionalities, and they also distribute power and temperature sensor lines that go into the pot interior. A crate housing electronics for the ToF detector (ToF DAQ Boards) will be placed under far stations. In between both stations, 212 m from the IP, there is a crate containing the second stage of the LV supply. It houses the dedicated cards with the radiation-hard voltage regulators, ensuring precise low voltage supply for trackers in both stations and for ToF electronics. The Optoboard module, which serves both stations, is installed in this crate. A passive distribution panel for re-connections of different cable types and signal lines is placed on top of the crate.

2. Detector Control System

The AFP detector and its infrastructure are supervised by the Detector Control System (DCS), responsible for the coherent and safe operation of the equipment. DCS provides tools to bring the detector into any desired operational state and continuously monitors its operational parameters, a subset of which can be archived in databases for further checks. Crucial parameters are guarded by the alarm system, with alarm threshold limits tuned by the experts. The DCS signals any abnormal behaviour and allows for manual or automatic actions. Lastly, it serves as a homogeneous interface to the detector and its infrastructure.

2.1 DCS software structure and tools

The ATLAS experiment uses the industrial Supervisory Control and Data Acquisition (SCADA) Siemens WinCCOA [7] system. A set of standards, tools and guidelines has been prepared for all CERN experiments in the framework of the Joint Control Project (JCOP) [8]. Furthermore, the ATLAS Central DCS [9,10] group provides the ATLAS-specific tools, components, rules and guidelines. The AFP DCS project architecture follows them and has been built to be integrated within the ATLAS Central DCS system. Its architecture is presented in Figure 2. The software responsible for all AFP DCS operations is running on AFP Local Control Station (DCS PC). The dedicated communication channel between the DAQ and DCS is used for passing health (see Sec. 3.8) parameters from Front-End readout chips.

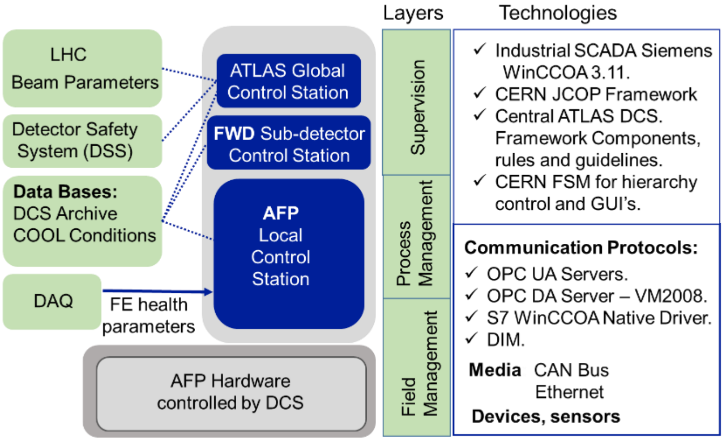

Figure 2. AFP DCS software structure and tools.

The DCS software consists of three layers. The Field Management layer establishes communication between different hardware units and the controlling computer. Ethernet and CAN bus serve as the field buses. OLE (object linking and embedding) for Process Control (OPC) [11] middleware allows the vendor independent hardware integration with the SCADA. Two types of OPC servers are used: OPC DA, working only on Windows platforms and OPC UA, used on Linux machines. The Distributed Information Management (DIM) [12] is an inter-process communication mechanism used for data exchange between different platforms. The AFP DCS uses it for reading/publishing RP movement data. The WinCCOA Native S7 driver is used to control the Programmable Logic Controller (PLC).

The Process Management layer is responsible for overall data processing, storing data to databases, mapping and calculations. The WinCCOA SCADA serves as the main software in this layer. The set of JCOP framework component tools facilitates integration with standard hardware devices and implementation of control applications.

The third layer, the Supervision layer is responsible for overall detector operation and visualization. The JCOP Finite State Machine (FSM) [13] toolkit is used to build a representation of the detector as a hierarchical, tree-like structure of well-defined subsystems, called the FSM nodes. The hierarchy allows a high degree of independence of the tree parts, enabling their concurrent use during the tests and integration phases, and control during the operation, either automated or user-driven. Alarm Screen tool is used for immediate display of any appearing alarms.

2.2 AFP FSM hierarchy

The AFP Finite State Machine tree is shown in Figure 3. The partitioning is based on functionality and/or geographic location within the detector. Each FSM unit represents a detector part, whose behaviour can be described with a limited set of states. A state of the FSM unit is calculated taking into account states of the corresponding children in the hierarchy. Commands are defined in order to operate the detector and can be issued at any level of the hierarchy. They propagate downwards, while the states are propagated upwards in the tree.

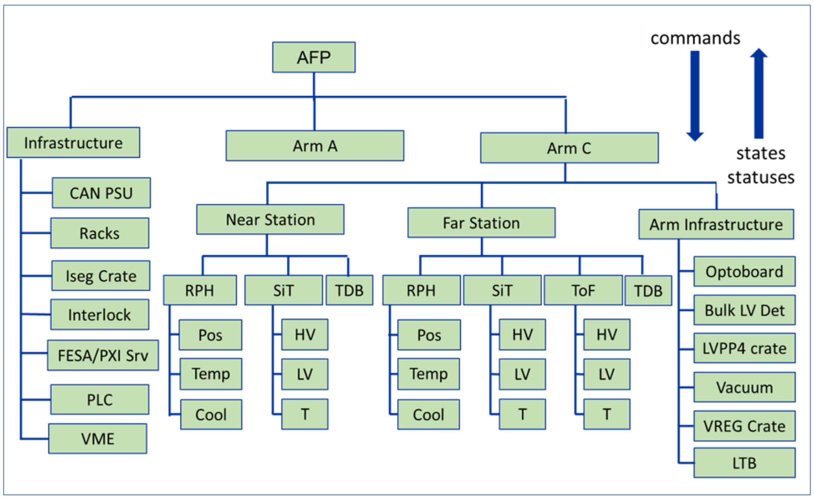

Figure 3. AFP FSM structure. Structure of Arm A is identical to Arm C, hence it is not shown here.

AFP is the top node, which shows the overall state of the detector. It consists of the Infrastructure, Arm A and Arm C nodes. The Infrastructure node includes services and devices dedicated to the whole detector. These are: the power supply for CAN Bus ELMB devices (CAN PSU), monitoring of the USA15 racks, monitoring and control of the HV crate (Iseg), the hardware interlock system, RP movement servers (FESA/PXI), a state of the PLC controlling secondary vacuum and cooling systems and control of the VME crate.

Arm A and Arm C nodes will be identical. Each FSM Arm node is split into the Far and Near Stations, and the Arm Infrastructure node, which contains the arm common services. These are (looking from the top): power supply, control and monitoring of the Optoboard, control and monitoring of the LV power supply crate (Bulk LV Det), monitoring of the LVPP4 crate, control and monitoring of the secondary vacuum (Vacuum), second stage for the Low Voltage power supply (VREG Crate) and powering of the Local Trigger Boards (LTB).

Near and Far Station nodes consist of: RPH – the Roman Pot structure with movement and cooling systems and pot temperatures measurements, SiT – the tracking detectors, with their low voltage (LV), high voltage (HV) and temperature (T) nodes and TDB (TDAQ Boards) node showing the LTB state. Far Station contains additionally a FSM node for the ToF detector.

2.3 FSM graphical user interfaces

Figure 4 shows example panels of the AFP graphical user interface. Two graphical operator's panels (primary and secondary) are associated with each FSM node in a hierarchy (Figure 4 (a)). The primary panel follows navigation within the hierarchy and is always displayed for the actual node, whereas the secondary one is opened on a request and will stay open through FSM navigation. Access control [14] implementation allows the presentation of different sets of widgets to the observer, the system operator or the expert. Technical panels (Figure 4 (b)) are used for deep hardware investigations and debugging. Alarm screen (Figure 4 (c)) shows instantly any monitored value which exceeds predefined limits.

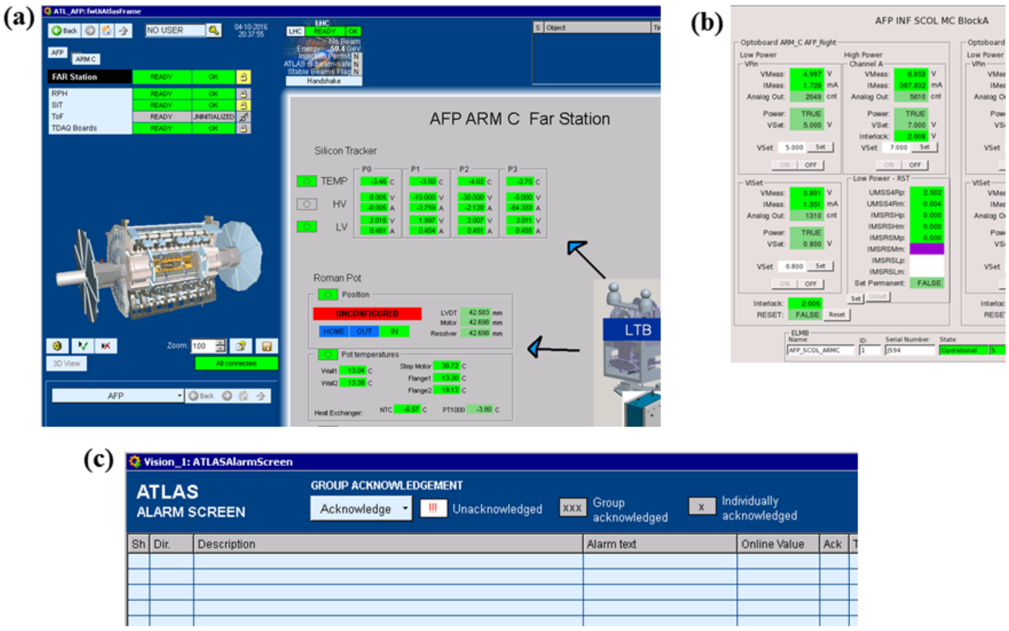

Figure 4. Examples of graphical user interfaces: (a) FSM panel: detector visualization and operation, (b) Technical panels - detailed actions, (c) Alarm screen - instant report of problems.

3. AFP hardware subsystems

The ATLAS multi-function I/O standard board, the Embedded Local Monitor Board (ELMB) [15] is widely used in the AFP for the hardware control and monitoring of different parameters, like temperatures, currents. It contains analog inputs, digital inputs/outputs, Serial Peripheral Interface (SPI) connectivity and provides a custom functionality. The device is the radiation and magnetic field tolerant. It can be embedded within custom-designed modules to allow connection of sensors of different types. The ELMB is CAN controlled and can be powered by a dedicated CAN Power Supply

Unit (CAN PSU). The ATLAS custom-developed CANopen OPCUA server is used for the integration with the AFP DCS.

The AFP infrastructure used for powering of the tracking detectors is virtually identical with the IBL one, and the applied control system follows partially IBL solutions [16].

3.1 Roman Pot movement system

The AFP Roman Pot movement and control [17] is under responsibility of the LHC CERN Control Center (CCC). The system consists of a real-time controller based on the National Instruments (PXI-FPGA) platform assuring a safe and proper motor control, and of a server application based on the CERN-developed Front-End Software Architecture (FESA) framework that ensures the interface between the PXI and LHC CCC control. Communication between the AFP DCS and the FESA server is done by means of the DIM system. The AFP DCS monitors the status of the movement system and pots positions and displays a related information. Two actions are available for the detector operator: the movement veto and the emergency extraction.

3.2 Secondary vacuum

A secondary vacuum inside the pot reduces the stress and deformations of the pot's window. It also prevents water condensation and icing, when the temperature inside the pot drops below 0^{o}C. The applied control system follows the solutions used in the ALFA detector [18]. Two pumps with the valves are installed in each arm. The system is controlled by the PLC Siemens 1200 [19]. The WinCCOA S7 native driver is used for the Ethernet-based communication between the PLC and the AFP DCS. Several manual or automatic operation modes of the vacuum system are available. Pressure values both in the pumps and in the Roman Pots are monitored.

3.3 Cooling system

The trackers and the ToF detector require cooling. A cooling system of Vortex Tube Air Cooler Split type [20] is used. Input air is precooled in the Air Cooler box and then passed to the second Vortex Tube located close to the pot. The air pressure for individual stations can be changed, and the valves can be remotely opened/closed. DCS monitors the pressure before the Air Cooler box and the temperature in the heat exchanger inside the pot. Additionally, each Air Cooler box is equipped with three temperature sensors, read out via the AFP temperature monitoring chain (described in Sec. 3.7). The same PLC is used both for the secondary vacuum and for the cooling control.

3.4 High Voltage system

High Voltage is used for the silicon sensors in the tracking detectors and for photomultipliers of the ToF detectors. The Iseg HV system [21] is used. It consists of the ECH 238 crate and two high precision modules: with -500V nominal voltage used for tracking detectors, and with -3 kV nominal voltage used for ToF counters.

The control and monitoring is performed via CAN Bus, by means of the Iseg OPC UA server. The JCOP framework component is used for the integration with the AFP DCS.

3.5 Low Voltage system

Detector modules require powering at a precise voltage level. Furthermore, protection of the Front-End chips against the overvoltage is necessary. LV power supply should then be located as close to the stations as possible. Installation of a standard power supply in the tunnel is not possible due to the radiation level and access availability. Therefore a two-stage low voltage system is applied: Wiener PL512 [22] power supply and LV-PP4 crate for the current measurement as the first stage, located in USA15. The Voltage Regulator (VREG) crate as the second stage is located in the tunnel. Wiener PL512 power supply contains 12 independent voltage channels. All channels are connected to the dedicated patch panel crate (LVPP4), which splits each voltage channel into four lines. ELMB measures the current for each line.

The 330 m long cables are used to connect LVPP4 outputs with LV boards sitting in the VREG crate located in the tunnel. Each LV board contains four independent channels with radiation-hard voltage regulator chips. They can be individually controlled. One LV board supplies the tracking detector in one station. A special controller board with ELMB of the non-standard firmware is used to control the regulators and to monitor their voltages. Four temperature sensors are installed and are read out via the AFP temperature monitoring chain (see Sec. 3.7).

Wiener PL512 power supply communicates over the Ethernet with the Wiener OPC DA server installed on the DCS computer. The server runs only on Windows platform, so Windows 2008 Virtual Machine (VM) in Linux machine was installed.

JCOP and ATLAS framework components are used for the systems integration with the AFP DCS.

3.6 Optoboard power supply

The optical converter board (Optoboard) needs three different voltages. Hence a dedicated, standalone power supply located in USA15 and controlled by the ELMB is used. One voltage is additionally routed through a dedicated board for protection of the optolink chip. The board contains the radiation-hard voltage regulators and is located in the VREG crate.

The ATLAS framework components are used for integration with the AFP DCS.

3.7 Temperature monitoring and interlock (Interlock Matrix Crate)

All temperature sensors installed on tracking modules, inside and outside the Roman Pots, inside the Air Coolers and the VREG crate, on the LTB's and Optoboard are connected to the Interlock Matrix Crate (IMC) located in USA15. The temperature sensors are restricted to Negative Temperature Coefficient (NTC) type.

In addition to the temperature measurement the IMC serves as an interlock system for the LV Wiener PL512 and HV Iseg. An interlock is triggered if the temperature exceeds a threshold value. The trackers, LTBs, VREG crate and Optoboard are protected by interlocks.

The device is ELMB controlled and the ATLAS framework components are used for its integration with the AFP DCS.

3.8 Front-End readout chips health parameters

Readout chips of the tracking detector (FE-I4B) and High Precision Time-to-Digital Converter (HPTDC) chips, used for the ToF counters do have a possibility to measure their internal parameters, like a temperature or a leakage current. The parameters, called the health parameters, are read-out by the AFP DAQ system and will be accessed by the AFP DCS in the following way: an OPC UA server which is embedded in the DAQ machine, acquires the health parameters from the DAQ via the dedicated Application Programming Interface (API) routines. The integration with the AFP DCS is done by means of the OPC client, which subscribes the data from the server. This part is under development.

4. Status

The AFP Detector Control System was installed in January 2016. It has been continuously operational starting from the detector installation in the tunnel and commissioning. It is developed together with the newly installed detector components. It operates stably and reliably. Since June 2016 it is integrated with the ATLAS Central DCS.

During the LHC 2016-2017 winter shutdown two stations of the second arm together with the trackers and the ToF detectors in both arms will be installed. The DCS will be modified and extended accordingly to serve and control the upgraded apparatus.

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