THE AFP DETECTOR CONTROL SYSTEM

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Abstract

The ATLAS Forward Proton (AFP) detector is one of the forward detectors of the ATLAS experiment at LHC/CERN aiming at measuring momenta and angles of diffractively scattered protons. Silicon Tracking and Time-of-Flight detectors are located inside Roman Pot stations inserted into beam pipe aperture. The AFP detector is composed of two stations on each side of the ATLAS interaction point and is under commissioning. The detector is provided with high and low voltage distribution systems. Each station has vacuum and cooling systems, movement control and all the required electronics for signal processing. Monitoring of environmental parameters, like temperature, is also available. The Detector Control System (DCS) provides control and monitoring of the detector hardware and ensures the safe and reliable operation of the detector, assuring good data quality. Comparing with DCS systems of other detectors, the AFP DCS main challenge is to cope with the large variety of AFP equipment. This paper describes the AFP DCS system: a detector overview, the operational aspects, the hardware control of the AFP detectors, the high precision movement, cooling, and safety vacuum systems.

INTRODUCTION

AFP [1], currently in commissioning phase, is a forward detector installed in the LHC tunnel away from the ATLAS [2] Interaction Point (IP). It consists of four detector stations, two in each side of the IP at 205 and 217 m. Both stations are equipped with a Silicon Tracking detector (SiT), while the one that is placed further from the IP contains, in addition, a Time-of-Flight detector (ToF). Each AFP detector (SiT or SiT+ToF) is inside of a Roman Pot that protects it from the LHC high vacuum with a secondary safety vacuum.

The SiT is made of four planes with a 3D pixel sensor connected to a front-end chip (FE-I4B) providing 336×80 pixels with a size of 50×250 μm^2 given a active area of 1.68×2.00 cm^2 where the readout is done at 40 MHz through a flexible printed circuit. The sensors are mounted in a structure separated by 10 mm between planes.

The ToF calculates the interaction vertex location by measuring the arrival time difference of the forward protons in the two arms with pico-second accuracy. It consists of quartz bars positioned at the Cherenkov angle with respect to the proton flight direction. The bars are in L shape and perform as radiator and guide material (LQbars [3]). The 4×4 LQbars are connected to a 4×4 pixel Microchannel Plate Photomultiplier (MCP-PMT).

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THE AFP MAIN DCS SYSTEMS

System Overview

The SIMATIC Siemens WinCC Open Architecture (WinCC OA) [4] is a Supervisory Control and Data Acquisition (SCADA) system, a commercial package chosen by the Joint Control Project (JCOP) [5] for developing DCS systems in all the LHC experiments. The JCOP goal is to provide standards for the use of DCS common hardware components, implementation policies, Back-End (BE) software and operational aspects for all experiments.

The AFP DCS [6] is hosted in a server (DELL Power EdgeR620) with Linux SLC6 as native operating system. The control interfaces of some commercial components work under Windows operating system so the server hosts also a virtual machine (VM) with Windows Server 2008.

To control and monitor the complete detector two SCADA systems under WinCC OA 3.11 were built. The main system hosted in the Linux server is the core of the AFP DCS. It manages communication with the hardware which is controlled by an Open Platform Communications (OPC) Unified Automation (UA) servers, like ELMBs (Embedded Local Monitor Board) [7] and high voltage system or by using native drivers, like Programmable Logic Controllers. It runs all control scripts, displays information, contains the Finite State Machine (FSM) and is the interface for the ATLAS DCS. A scattered project with a client for OPC Data Access server is running in the VM.

The hardware is located in 3 places: (i) at the detectors and Roman Pots, (ii) at the crates with the readout electronics, voltage regulators, optoboards, and the AirCoolers on the tunnel floor below the detector, and (iii) at the power supplies and the computer in the USA15 service cavern.

High Voltage Power Supply

The high voltage is provided by an ISEG power supply crate equipped with two modules with 16 channels each. The ISEG modules supply power to the silicon sensors of the SiT detector (-500 V) and to the ToF photomultipliers (-3000 V). The control and monitoring is performed via CAN bus using OPC UA server.

Low Voltage Power Supply

A two-stage low voltage power supply system (based on Insertable B-Layer (IBL) [8] solution) was developed for dedicated powering and protection for overvoltage. Wiener PL512 power supply and a dedicated patch panel for precise current measurement as a first stage located in USA15 service cavern and Voltage Regulator (VREG) crate as a second

stage located in the tunnel in between stations. The VREG crate contains a VREG Controller, LV and Vvdc VREG boards. The LV VREG boards supply the FE-I4 chips and ToF electronics, the Vvdc VREG board delivers the proper voltage for the optoboard, while the VREG Controller card controls the regulators and monitors the voltage levels with ELMB of non-standard firmware.

Wiener channels are connected to LV VREG boards via a dedicated patch panel which splits one output from the Wiener power supply into four parallel lines and measures current for each line. The measurement is done by means of ELMBs. One line feeds one channel in the LV VREG board.

Wiener Pl512 power supply contains 12 independent voltage channels, 10 channels with an output voltage range up to 17 V and 2 channels with the range up to 24V. All channels have hardware interlock capability. It communicates over the Ethernet with the Wiener OPC DA server installed on the Windows Virtual Machine.

The SCOL (Supply Control - OptoLink) is a standalone device located in USA15 that supplies power to the optoboard modules with three different voltages, one of these voltages feeds the Vvdc VREG board.

Temperature Monitoring

Interlock Matrix Crate (adapted from IBL) is used in order to provide protection to the detectors and electronics against overheating by switching off the power supply related to the source of over-current or over-temperature. This system is hardware based and the state is monitored by the DCS via ELMBs.

Interlock Matrix Crate performs temperature measurement in the detector area, electronic modules located in the tunnel and cooling system by means of ELMBs. ELMBs are CAN controlled. Hardware connection to the computer is done by means of a dedicated CAN-to-USB interface (SYS-TEC), which serves also for other CAN-controlled devices, like High Voltage ISEG. The integration with the AFP DCS is done with the OPC UA server. Interlock Matrix Crate ELMBs are supplied by a dedicated CAN Power Supply Unit. Both Interlock Matrix Crate and CAN Power Supply Unit are located in the USA15 service cavern.

Vacuum and Cooling

The same Siemens Programmable Logic Controller (PLC) is used for monitoring and control of the Vacuum and Cooling systems. The air-cooling is fed by the main air supply distribution system and the secondary vacuum is made by pumps.

The cooling system controls the temperature in the Roman Pot interior to avoid overheating of the detector components. It is described in detail in Section **COOLING SYSTEM**.

The secondary vacuum works as a security vacuum that minimizes the bending of the thin window of the Roman Pot caused by the pressure difference between the pot interior and the primary LHC vacuum in the exterior. The AFP DCS for the vacuum system was built based on ALFA DCS

[9]. The Vacuum system is described in detail in Section **SECONDARY VACUUM SYSTEM**.

Movement System

The AFP DCS task in the movement system is to monitor the Roman Pots positions inside the LHC beam pipe. It was built based on ALFA DCS. More details on this system can be found in Section **MOVEMENT SYSTEM**.

DETECTOR CONTROL SYSTEM

The Detector Control System (DCS) [10] was built using WinCC OA 3.11 package. A control station (PC), with WinCC OA, runs a Project with a number of processes responsible for the operation. WinCC OA is a device-oriented software with the parameters/variables organized such as hardware channels of the device (temperatures, currents, etc). From the parameters/variables it is possible to attach configurations in order to setup alert, archiving and addressing (for hardware).

WinCC OA panels describing parts of the system were developed and serve as graphical user interfaces. A FSM allows to navigate through these panels, calculate states and status of the detector and send commands in an easy way for a non expert operator.

FINITE STATE MACHINE

The DCS back-end is mapped onto a hierarchy of FSM [11] elements where states are propagated upwards and commands are propagated downwards in the hierarchy allowing the operation of the complete detector through a single FSM object at the top of the hierarchy. This is a powerful tool in the DCS that allows to monitor and control a huge number of parameters simultaneously.
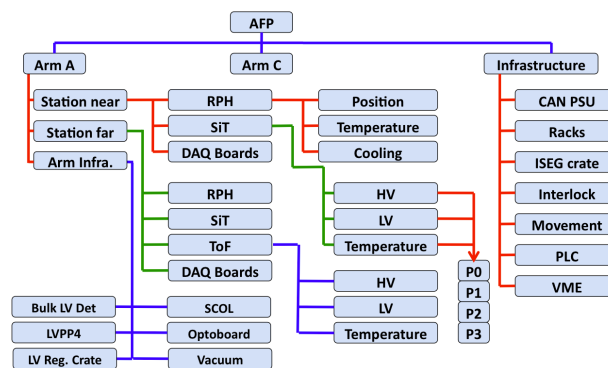

Figure 1: FSM architecture for the AFP DCS.

Figure 1 shows the FSM architecture for the AFP DCS where the top node is divided in the two arms (ARM A and ARM C). The two arms contain branches for the near and far stations, with the correspondent detectors and sub systems monitor/control, as well as their infrastructure. The common detector infrastructure is at the same node level as the Arms.

DATA HANDLING

Data Archiving

Relevant data related with the detector operation (values of voltages, currents, temperatures, etc) are stored in an Oracle online database, according to a smoothing mechanism based on value and/or timestamps, in order to avoid a huge amount of stored data.

To be available outside the ATLAS technical network the data is stored in an offline database. Data suitable for physics analysis and data quality evaluation is stored in a Conditions Database.

Alert Handling

The alert handling mechanism of the AFP DCS provides alerts to the operator that can indicate a failure in the hardware or trigger an information, that a monitored parameter is outside correct values. The alerts are divided in classes according to their severities (for example: WARNING, ERROR and FATAL) that reflects how far the monitored parameter is outside a correct value.

An alert can also trigger a notification (email and/or SMS) to the operator. This is done using a control script that checks the status of some sensitive parameters of the detector.

COOLING SYSTEM

The electronics inside the secondary vacuum of the Roman Pot, in particular the 3D Silicon Tracking electronics, requires cooling. Between the Silicon Tracker and the Time-of-Flight detector there is approximately 12 W generated inside the Roman Pot. This heat is conducted to a heat exchanger that receives cold air from a Dry Air Vortex Cooling System using a AirCooler device capable to deliver 450 L/hr of cooled air with a temperature drop of $\Delta T = 50°C$. The AirCooler uses a combination of vortex tubes and heat exchangers to achieve the desired cooling effect.

Each detector arm has its own cooling system which regulates the air flow from the AirCooler into the heat exchanger inside the Roman Pot. The pressure flow is remotely controlled by electrovalves that acts on a pneumatic valve in order to open or close it, and on a pressure regulator inside the AirCooler [12].

The control and monitoring of the cooling hardware is done via a Programmable Logical Controller (PLC) which is a digital computer largely used for automation in industrial electromechanical processes. The chosen PLC for AFP is a S7-1200 from Siemens. The communication between the PLC and the DCS is through the native driver WinCC OA S7 in order to send data to the PLC and poll data from it via TCP/IP.

The AFP DCS is capable to control and monitor the electrovalves, read the pressure value coming from a pressure sensor located close to the AirCooler box and measure the temperature in the heat exchanger inside the Roman Pot through a PT1000 sensor.

The cooling system works either in Manual mode, in which the operator has full control of the system, or in Automatic mode, where the operator selects the set temperature and the PLC controls the pressure regulator through a PID (Proportional Integral Derivative) functionality. Figure 2 shows the behavior of a temperature perturbation in the both modes. In cases of temporary decrease or increase in power consumption, for example in a power cycle, the Manual mode recovers to the desired temperature faster then the Automatic mode. However if the decrease or increase in power is not temporary, for example detector shutdown, the Automatic mode is able to keep the same detector temperature by adjusting the air flow in the heat exchanger while in Manual mode the operator has to adjust the air flow manually. Also during collisions the temperature inside the RP grows and the automatic regulation helps to keep constant temperature in the heat exchanger, hence in the detectors.

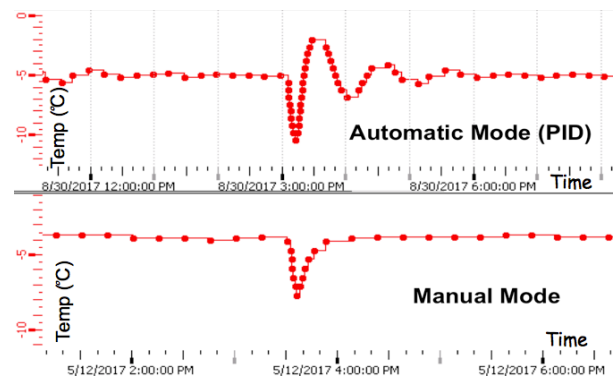Values of a pressure and a temperature in the heat exchanger are archived.

Figure 2: Behavior of temperature perturbation in both modes in the heat exchanger measured by a PT1000 sensor.

SECONDARY VACUUM SYSTEM

The Vacuum System for the AFP is divided into two similar systems, one for each detector arm. It is composed by pumps, electrovalves and pressure sensors controlled and monitored by the same PLC which is used in the cooling system. Each system provides vacuum for both stations with two pumps and two electrovalves for redundancy purposes and to improve the live spam of the components. On both sides of the electrovalves (pump and pot side) there are pressure sensors for monitoring. There is also a pressure sensor in the pot side.

The vacuum software in the PLC controls the pumps and electrovalves according to the pressure readings. The top plot in Figure 3 shows the operation sequence of the pump. When the pressure in the pot side reaches a given threshold, the electrovalve continues to be closed but the pump starts running (A). After 10 seconds the electrovalve is opened (B) which exposes the atmosphere in the pot side to the extraction by the pump. The volume to be pumped from the pot side is much higher than from the pump side so it takes

time to reach the lower pressure limit (curve from B to C). When the lower limit is reached the electrovalve is closed (C) and after a while the pump stops (D). The pressure rises because of the expected leaks in the pump.

The vacuum system does not supply a constant pressure value to the Roman Pot inside. Such would require a constant running of the pumps, which would decrease the life time of the system itself. The pressure in the pot side is oscillating between 10 and 40 mbar which can be seen in the bottom plot of Figure 3, with a periodic action from the pumps.
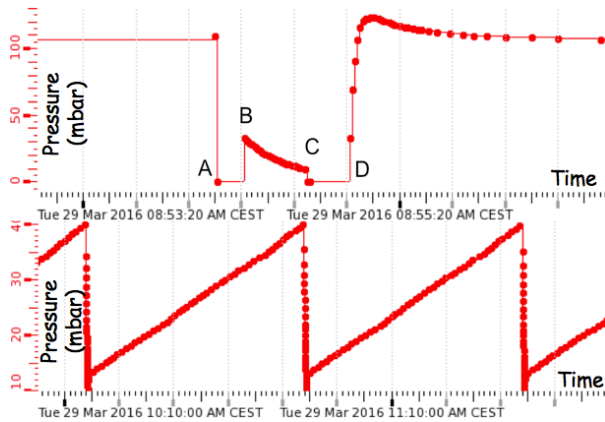

Figure 3: Top: Pressure from the Pump side as a function of time. (A) Pump ON, (B) Eletrovalve OPEN, (C) Electrovalve CLOSE and (D) Pump OFF. Bottom: Pressure from the Roman Pot side.

PLC controls and monitors the vacuum system in an autonomous way. The AFP DCS not only monitors parameters (like pressure sensors and states of electrovalves and pumps) but also selects the working modes of the vacuum system. The available modes are:

- Alternate - Both pumps work alternately in different iterations

- Both - Both pumps work simultaneously in all iterations

- Pump1 - Working pump is always pump 1

- Pump2 - Working pump is always pump 2

- Manual - The operator has the possibility to open/close the valves and start/stop the pumps.

There are two types of modes that can be selected through the AFP DCS. The Manual mode is a low level handling because it is the operator that fully controls the system. The Automatic modes which represent the rest of the modes (Alternate, Both, Pump1 and Pump2) are high level handling from the DCS side because they only select how the system should work. In the Automatic mode the DCS is not responsible for the opening/closing of the electrovalves or the starting/stoping of the pumps, this is managed by PLC programing.

A dedicated technical panel was developed for the first tests in controlling and monitoring the vacuum system
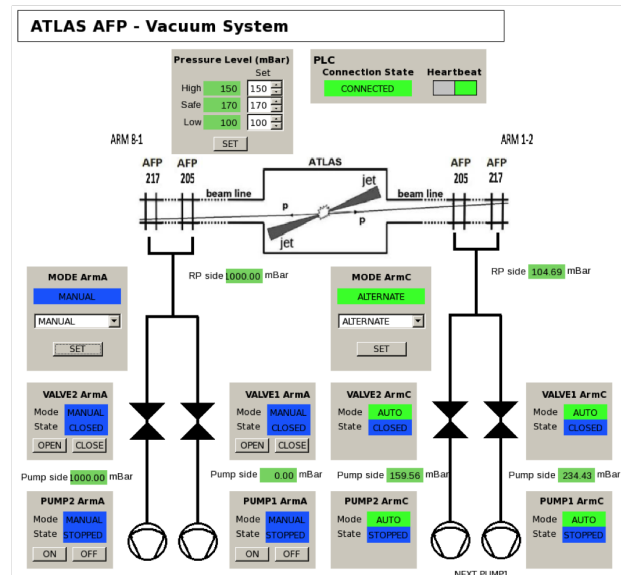

Figure 4: Technical panel for the AFP Vacuum System.

through DCS (Figure 4). The connection state to the PLC, the PLC heart beat, to monitor and setup the thresholds for the pumping start/stop, state of electrovalves and pumps, pressure readings and control of the pumps and electrovalves can be seen in this panel.

All pressure readings are archived. An alarm of severity WARNING and/or FATAL is defined for RP pressure. It appears, if the pressure value exceeds predefined alarm thresholds.

A malfunction in the vacuum system may have serious consequences in the detector, so a SMS/E-mail notification service is triggered if any pressure reading has an alarm or if the connection to the PLC is lost. This service consists of a control script that checks for pressure alarms and connection state of the PLC.

MOVEMENT SYSTEM

The AFP DCS task in the movement system is to monitor the Roman Pots positions inside the LHC beam pipe. Each station has its own horizontal movement with a step motor resolution of 5 μm. Radiation-hard toggle switches were implemented for movement range and after limits and electrical stop switch for calibration.

The monitoring and control of the stations movement along the beam pipe is a standalone system fully integrated with the LHC control system [13]. There are two systems involved in the movement control: a National Instruments PXI, which is a front-end real time control application and a Front-End Software Architecture (FESA) server that hosts the DNS (Domain Name System) for the AFP DCS connection and interface to the CERN Control Center applications, as it is schematically shown in Figure 5.

The AFP DCS monitors positions, alerts, states and actions. It accesses the subscribed raw data through the DIM (Distributed Information Management) [14] server and, by
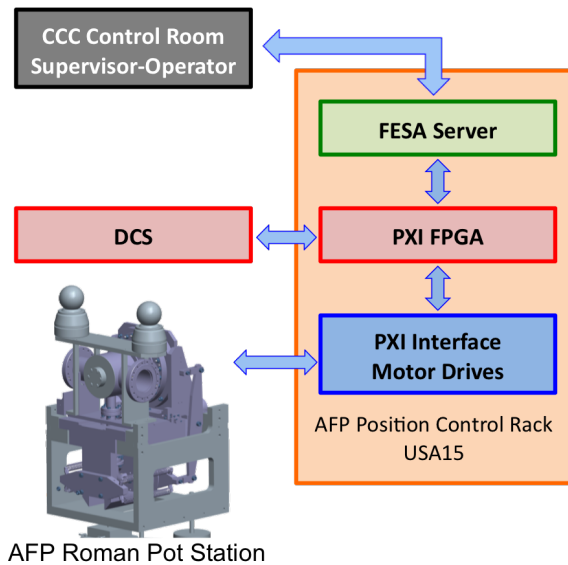
Figure 5: Movement operational scheme.

a control script, it updates the data class which contains the data organized by station. Information arriving to the DCS is related not only to detectors position but also to switches, Roman Pot state, servers status and alerts.

The position information is measured by three systems, LVDT (Linear Variable Differential Transformers), step motor and Resolver. If the movement control is not initialized properly there will be divergencies between the three measurements. A control script looks for mismatches in the three systems and sets a flag that raises an alarm.

The only actions which can be performed by the AFP DCS via publishing commands to the PXI are emergency extraction of the RP and inhibit of the RP movement. All other movement actions are done from the CERN Control Center and the AFP DCS only monitors. Figure 6 shows the detector movement when it goes from the garage position (A) to a position B in the beam pipe; the detector stays in the same position for some time and then starts to move (C) to the initial position (D). The same procedure is repeated.
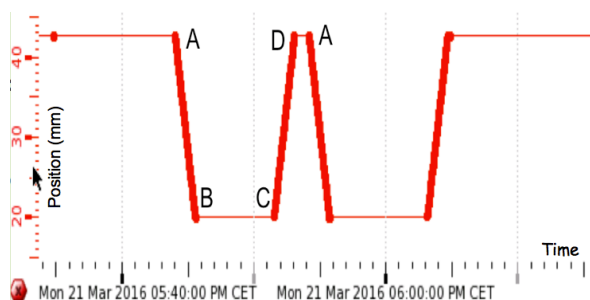

Figure 6: Plot of the detector movement as a function of time: (A) start move IN, (B) stop move IN, (C) start move OUT, (D) stop move OUT and in garage position.

RP position which allow to take physics data are tagged by DCS and are passed to DAQ (Data Acquisition) via DAQ to DCS communication channel.

CONCLUSION

Currently, the AFP detector is under commissioning, it participates in several physics runs and data taking successfully. The AFP DCS includes a large variety of different systems and is successfully integrated with the ATLAS detector. All the AFP DCS subsystems are concurrently under developments and are capable to fulfill all detector requirements on monitoring and control including the Vacuum, Cooling and Movement systems.

ACKNOWLEDGEMENT

REFERENCES

[1] *ATLAS Collaboration 2015 ATLAS Forward Proton-Phase-I Upgrade*, Technical Design Report, ATLAS-TDR-024

[2] *ATLAS Collaboration*, 2008 JINST 3 S08003.

[3] L. Nozka, *Construction of the optical part of a time-offlight detector prototype for the AFP detector*, Jrn-Dir, `http://dx.doi.org/10.1364/OE.24.027951`

[4] Siemens, SIMATIC WinCC Open Architecture, `http://www.siemens.com/wincc-open-architecture`

[5] O. Holme, M. Gonzalez Berges, P. Golonka and S. Schmeling, *The JCOP framework, proceedings of the 10th International Conference on Accelerator and Large Experimental Physics Control Systems*, Geneva, Switzerland, 2005.

[6] E. Banaś et al., *Detector Control System for the AFP detector in ATLAS experiment at CERN*, ATL-FWD-PROC-2017-001, accepted for publication in Journal of Physics Conference Series (JPCS) `http://cds.cern.ch/record/2244554/files/ATL-FWD-PROC-2017-001.pdf`

[7] B. Hallgren, *The Embedded Local Monitor Board (ELMB) in the Front-End I/O Control System, 7th Workshop for LHC Experiments*, Stockholm (2001).

[8] *ATLAS Collaboration 2010 ATLAS Insertable B-Layer Technical Design Report*, ATLAS-TDR-19

[9] L. Seabra et al., *ALFA Detector Control System*, 2015 IEEE International Conference on Industrial Technology, pp. 93-98

[10] A. Barriuso Poy, *The detector control system of the ATLAS experiment*, 2008 JINST 3 P05006.

[11] Franek B and Gaspar C 2004 *SMI++ - Object Oriented Framework for Designing and Implementing Distributed Control Systems*, IEEE Trans. Nucl. Sci. 51 513

[12] Vacek V and Doubek M 2015 *The aircooler device – a flexible and mobile cooling solution for lower level heat loads* Proc. of the 24th IIR International Congresses of Refrigeration

[13] David P-Y, Massol N, Pons X, Ravat S, Rijssenbeek M, Sicho P, Trzebinski M and Wenig S 2016 *Specification and Validation of the Motion Control System of the ATLAS Forward Proton Roman Pots* ATL-UR-ER-009

[14] C. Gaspar, M. Dönszelmann and Ph. Charpentier, *DIM, a portable, light weight package for information publishing, data transfer and inter-process communication*, Comput. Phys. Commun. 140 (2001) 102.