CONSOLIDATIONS ON THE VACUUM CONTROLS OF THE CERN ACCELERATORS, DURING THE FIRST LONG SHUTDOWN OF THE LHC

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Abstract

For two years (Spring 2013 – Spring 2015), the LHC went through its first long shutdown (LS1) [1]. It was mainly motivated by the consolidation of magnet interconnects, to allow operation with 6.5 TeV proton beams. Moreover, around the accelerator complex, many other systems were repaired, consolidated or upgraded, and several new installations came to life.

The standardization of vacuum controls has progressed in the injectors, with the renovation of most of their obsolete equipment.

In the LHC, many new instruments were added, the signal transmission integrity was improved, and the exposure to radiation was reduced in critical places. Several developments were needed for new equipment types or new operational requirements.

INJECTORS & LHC CONSOLIDATIONS

Complex PS

The LS1 was an opportunity to extend the standardization of vacuum controls to the Proton Synchrotron ring (PS), the Antiproton Decelerator (AD), and the nTOF experiment. The legacy controls were updated to the same PLC/SCADA-based architecture as in the other machines. Only the pumping groups of the PS complex remain to be upgraded, during the following years. [2]

The existing controllers were either upgraded, or replaced by newer generations, connecting to the PLC directly through Profibus or via remote-IO stations. This involved 500 cables and 700 instruments.

Above all, a large effort was put in the production of complete and up-to-date documentation on the control system layout and on its components technical details.

Linac2, at the head of the proton acceleration chain, received a new set of six pumping groups. These were especially developed to compensate for the dying old ion pumps, helping it to survive until replaced by Linac4.

SPS

In the SPS, controls renovation was applied to its injection line, the interfaces for the Beam Interlock System, and COLDEX.

Several new gauges and valves were added, for a few new sectors. Furthermore, all racks and cables were prepared for the new re-sectorization of all the ARCs.

Campaigns for replacement of aged cables were performed in several places. In total, some 300 cables were replaced, and 200 other were newly installed, mainly for some 80 new instruments.

LHC

About 600 cables and 400 gauges, valves, and pumps, were newly installed in the LHC, together with the corresponding interlocks. Some of them required specific controls developments, treated in detail further down.

The signal integrity has been revised and improved, for the gauges in the ARCs and for the bypass-valves. To mitigate radiation effects in Point7, 27 racks full of equipment were dismounted and relocated into a less exposed zone, while 400 cables had to be extended. These subjects are treated in another paper [3].

During the second half of 2014, six teams of two people were full-time involved in the commissioning of all controls and instrumentation of the LHC. All instrument chains were fully tested; and calibrated when necessary. Documentation was updated about racks layout and interlocks cabling.

During the LHC global check-out, systematic tests were performed on all interlocks, to every sector valve, and to the beam interlock system, automatically from SCADA.

All in all

In total, more than 2 900 cables and 1 500 instruments were commissioned in the accelerators consolidations and new projects. The controls team had to be reinforced by 50%, mainly with engineers from collaborating Institutes, trainees, and technicians from industrial support. The main challenges were the coordination of field activities with access restrictions and other teams' tasks, and having each machine commissioned and ready in time for beam.

DEVELOPMENTS FOR PUMPS

NEG Pumps

A Non-Evaporable Getter (NEG) is a highly reactive and porous material; it needs to be activated, by heating under vacuum, with a suitable temperature and duration. The recommended activation temperature is around 475 ºC, corresponding to 6A under 16V, for 1 h.

To increase pumping speed in critical equipment in the LSSs of the LHC, NEG cartridges (Capacitorr D400 2 from

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SAES™) were installed, with their activation cycle remotely controlled.

The DELTA™ SM6000 power supply (300V x 20A) is interfaced to the PLC via Profibus. It would feed up to 18 cartridges in series, if it were not for the voltage drop on the long cables. In practice, less than 10 are installed.

Several series of cartridges can be activated from the same supply, but at different times; a multiplexer crate steers the power to one of the series at time, via relays operated from PLC digital outputs.

Through Profibus, the PLC sets the required current on the power supply, which automatically adjusts the necessary voltage. The PLC will only set the power ON if the pressure is below 1e-3 mbar. Several operation modes, parameters, errors and warnings are implemented.

Sublimation Pumps

A Titanium sublimation pump consists of two Ti filaments in a cylindrical stainless steel vacuum chamber. A power supply, custom-designed in 1994, heats one of the filaments to the temperature of sublimation of Ti, in order to coat the inner surface of the chamber, which can then start to absorb the residual gases.

As the pumping efficiency reduces with time, the sublimation process must be repeated periodically. The power supply has two modes of operation: degassing, where both filaments are powered with a given current, for cleaning; and the actual sublimation of one filament, for a given time. It is hardware interlocked on Penning gauge, preventing any powering above 1e-7 mbar.

Remote access through PLC has now been implemented for PS, AD, and will later be extended to the LHC. The PLC sends binary commands and analog set-points, and receives binary status and analog feedback, through ET200™ remote-IO stations; each station can handle 8 devices. From the SCADA, the operator can define the set-points and the duration of the sublimation periods; recipes are available for repetition cycles, for one or several pumps.

Gas Injection in LHC

A prototype of the Beam Gas Vertex (BGV) detector has been installed in the LHC-LSS4L during LS1. This is a non-invasive beam size measurement instrument. It requires a gas injection system for neon or argon.

The control system for this gas injection is similar to the one used for the two Beam Gas Ionization (BGI) detectors, previously installed on both sides of Point4. Neon gas is injected into the BGI vacuum chamber and then ionized to measure beam emittance on LHC.

For both BGI and BGV applications, the gas injection system is composed of a standard pumping group [4], an analogue valve connected to the gas bottle, and an on-off injection valve connected to the beam pipe. The injection process is handled by a sequencer and operation modes. This PLC-based control achieves a safe and automatic gas injection without the need of a specialist in vacuum and injection techniques.

Gas Injection in Linac4

In 2014, LINAC4 had a new system to inject H2 gas in the Low Energy Beam Transport vessel, for the measurement of the beam current and size. It uses a commercial fine-dosing thermo-valve and its control unit, a primary pump and two on-off valves. They are all connected to a S7-300 PLC, which runs a sequencer and operation modes. The process starts with an isolated mode, to avoid accidental large gas flow that would damage vacuum and beam instrumentation. Then the process can run either in tuning mode (pressure set-point defined in vacuum SCADA) or nominal mode (pressure set point defined by the beam transfer controls).

Cryogenic Pumps

In NA62, seven large and fast Cryogenic pumps are used to reach 1e-6 mbar, by pumping at 100 000 l/s. The process is managed by a proprietary controller (PCA700C from HSR™). Unfortunately, no Profibus interface is available; one controller connects to the PLC via RS-232 and a Profibus gateway; the other controllers are chained with that one, on a token-ring network.

At first, this communication did not work due to a bug in the firmware; it was eventually fixed by the manufacturer, although with some delay for the project.

DEVELOPMENTS FOR GAUGES

Full-Range Gauges

In radiation-free zones of NA62 and HIE-ISOLDE, Pfeiffer™ MPT200 full-range gauges have the signal conditioning and Profibus interface integrated; this reduces cabling costs and offers increased functionality, such as status information and commands directly available on the PLC, without passing through dedicated IOs. The MPT200 comprises a Pirani and a Penning gauge to cover 1e3 to 5e-9 mbar, and switches automatically between the gauges.

After some issues with the evolution of the connector types for Profibus and for power, the gauges performed well. There are two operational modes which, while changeable during the configuration of the device on the Profibus network, cannot be modified during operation.

Thermocouples

800 E-type thermocouple channels have been installed around the machine, for warm magnets and collimators. The measurement covers -40 to +750 ºC, with absolute accuracy of +/-2 ºC, and is shown with 0.1 ºC precision.

Specific 16-input analog modules in Siemens ET200 remote IO-stations, convert the thermocouple voltage into temperature, before sending it to the PLC, who makes them available on the SCADA.

A new instrument-type was defined in Vacuum-DB and developed in the PLC, together with a SCADA panel grouping the 16 channels of each analog input module. There are no commands or interlocks associated to them.

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Passive Gauge Controller (TPG)

The TPG300™ gauge controllers are remotely managed by a PLC function created in 2003, never updated since 2007. With the rising number of devices in the system, up to 40 per PLC, some limitations emerged; these are mainly due to the slow polling rate of SCADA to PLC, together with the increasingly slow scheduling of TPG access from PLC.

To visualize on the SCADA all parameters and status of a single TPG, it may take up to 4 minutes, as each value is individually requested to the PLC, and then to the TPG; idem for parameter changes.

In order to keep track of parameter changes by the operators, a daily script gathers the information of all TPGs in each accelerator. This is now taking more than 10 h, and may fail in at some occasions.

A new PLC function was developed and is under test in one of the LHC points. Each PLC cyclically requests all the parameters and statuses of all TPGs connected to its Profibus network; all data is read and logged by the SCADA, and is fully refreshed in the background every 1 to 5 minutes. The historical follow-up of TPG parameters and statuses will thus be directly and immediately available in the SCADA's archives, with no need for heavy daily extraction by an external script.

Cryo-Maintain Interlock to Sector Valves

A temperature increase in one superconducting magnet of the LHC may lead to a pressure rise, propagating into neighboring vacuum sectors. The sector valves around magnets in critical zones have been software-interlocked on the cryogenic conditions. In this way, the loss of "Cryo-Maintain" status will isolate the corresponding sector, avoiding the propagation of the pressure rise.

The cryogenic status for the concerned zones is read directly by the vacuum PLCs in dedicated data-blocks of the cryo-PLCs. An incremental watch-dog is used to assure data validity. Of course, this interlock is not treated by the valves controller if the beam is present.

PROJECTS

COLDEX

In the SPS, the Cold Bore Experiment studies the beam pipe coating with amorphous carbon, under cryogenic conditions. Installed in a by-pass line, on top of two sliding platforms, it is moved into the beam line during experimental periods, and out of the beam for normal SPS operation [5]. The two old step-motors were replaced by new ones, and the old controls gave way to a Siemens S7-300 PLC, integrated in the SPS vacuum control system.

Operation can be manual or automatic, with check and compensation of differences in the advancement of each motor. Each platform provides feedback on the analog position and on the two end-switches.

To move into the beam line, the vacuum sector valves around the experiment must be closed, and the neighboring bumper magnets must be off. For improved security, the operation cannot be done remotely, and requires a physical key on the controller to enable it and to assure the magnets are not powered. A portable touch- panel provides interface to the system from the tunnel, near the experiment. The renovation of the motor control system was extended to the experiment´s vacuum instruments. All can be remotely monitored on the SPS SCADA, and statuses are available for other systems.

Given the importance of amorphous carbon coating for the project HL-LHC, the COLDEX experiment and its controls will continue to evolve in the near future.

SUBU

This Chemical Polishing machine for the surface treatment of superconducting RF cavities was developed in 1989. It was based on Siemens S5 PLCs and a custom HMI, running on Win-3.11. With time, the S5 product line had been discontinued, the HMI hardware was failing and not repairable, the HMI software was running on an obsolete OS, and the PLC code was un-documented. [6]

The challenge of this project was the nearly non-existing documentation, which led to a complete reverse-engineering of the machine: consulting with the operator to understand the process and the plant hardware; visual inspection of the sensors, actuators, and wiring; and re-writing the process description and all electrical diagrams.

The status of the field devices (valves, pumps, sensors, containers) was evaluated and, as it was judged satisfactory after minor reparations, left in operation.

The old control system was completely decommissioned and the new one was developed from scratch, targeting Siemens S7-300 PLCs and WinCC-OA SCADA, under the UNICOS framework, like done before for the ISOLDE complex. As chemical Polishing is a continuous process, the functionalities provided by the UNICOS-CPC are perfectly suited.

Furthermore, because the development in UNICOS is a well-standardized practice, maintenance work and eventual changes can be performed more easily by third parties; also, the development methodology forces the developer document the work thoroughly, resulting in quality documentation that always proves useful.

NA62, AD, LINAC4, HIE-ISOLDE

In NA62, the beam vacuum and the associated controls were completely renovated, and then commissioned during 2014. The new controls architecture follows the framework already used in the LHC and Injectors. It also incorporates a few novelties, which required specific developments in the PLC and SCADA. The hardware is described in [7] and the software in [8].

In AD, many consolidations were completed during LS1: gauges, valves, and ion pumps. The experiments racks were already moved to free space for ELENA installation.

The controls of Linac4 and HIE-Isolde have both been evolving, as new sectors and their instrumentation are added and commissioned. In parallel, the respective test-stands require maintenance and development.

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FROM LS1 TO LS2

The next long shutdown (LS2) foreseen for 2019-20 will be dedicated to: Injectors upgrade; LHC maintenance and consolidation; HL-LHC activities anticipated from LS3. Some tasks will use the next three Year-End Stops.

In parallel, several new installations are under way too, like Awake, Elena, etc.; HIE-Isolde will have more cryo-modules; Isolde controls will be consolidated.

In AD, the final consolidations will be: the integration of cryo-compressors for the RF cavities, together with the temperature of their cold heads; the replacement of the old gas injection system by a new one, similar to LHC-BGI; and the implementation of functions like remote-reset and opening of fast valves.

Important developments, to be considered or started, are: wireless communication for mobile equipment (fieldbus vs. 4G+); industrial ion pump controllers vs. upgrade of old ones; new rad-tol electronics for gauges in the arcs; improved design of sector valve controllers.

Also during LS2: support to vacuum mechanical activities and bake-out; calibration, alarm setting, interlock checks; test and commissioning of all instruments. The workload will require substantial manpower reinforcement, expected to be higher than for LS1.

Injectors

Around the complex PS, during the 3 years before LS2, the pumping groups, ion pumps, and their controllers, will be replaced or upgraded. Linac4 will have a full Sector Test in 2016. During LS2, the connection of Linac4 to the PSB, replacing Linac2, will induce layout modifications.

The SPS ARC re-sectorization should be accomplished before LS2. LSS6 will receive a test station for crab cavities, as part of the studies for High Luminosity LHC. There will be modifications in the layout of several zones, with associated cabling campaigns. The grounding of ion pumps will be consolidated. The racks layout will be reorganized, as it was done in BA4 during LS1.

LHC

In the LSS, the turbo pumping groups and their controllers will be progressively renovated until LS2; the controllers in the ARCs will be changed during LS2. Additional turbo pumps will be installed on the beam kickers.

The controllers for mobile pumping groups must be upgraded, due to obsolescence of the PLCs. The control system of VELO will be renovated, possibly before LS2.

In general, important layout modifications will occur in almost all the LSS, leading to large cabling and connection campaigns, and significant modifications in the racks.

Controls Framework

Following the effort of standardizing the naming of all vacuum controls equipment, the instruments will be next. The implementation of both these naming conventions will involve considerable work on the electrical and mechanical diagrams, databases, and SCADA.

During LS1, a large volume of information was collected, about the layout of vacuum controls and the assets installed in the machines. The organization and formatting of this data is in progress, to later be uploaded into the CERN Layout and Asset-Management databases.

The controls issue-tracker (VTL), together with the handling of vacuum intervention work-orders, is being integrated in Infor-EAM, the CERN asset management system. The tracking of software issues and developments will use Atlassian JIRA. SVN™, used since 2012 for the versioning of SCADA applications, has been extended to the PLC.

SCADA archiving in Oracle (RDB) has been introduced; until the depth of one year is reached, the old archiving system will run in parallel. Some SCADA new features will next be implemented: dynamic calculation and trending of valve reaction times, improved main synoptic warnings for sector valves, and faster acquisition and display of TPG status and parameters.

A new major version (3.14) of WinCC-OA SCADA will be deployed in 2016; it will include a native user interface for mobile devices, dynamic resize of panels, and improved historical data collection.

The UNICOS framework is present in many domains at CERN, who profit from centralized development and support. It is already used for vacuum controls in the Isolde complex and in surface treatment installations.

However, it lacks several vacuum-specific functionalities and field-objects. A convergence project is being established: a minimum set of field objects will be developed and deployed in Isolde complex. In parallel, the SCADA functionalities will be migrated to UNICOS, and progressively integrated. Also, the Time Stamp Push Protocol (TSPP) should soon be implemented.

Linac4 could be a test-bench for the full integration, before global deployment in all accelerators during LS2.

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