# THE CONTROL SYSTEM OF CERN ACCELERATORS VACUUM [ LS1 ACTIVITIES AND NEW DEVELOPMENTS ]

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*Abstract*

After 3 years of operation, the LHC entered its first Long Shutdown period (LS1), in February 2013 [1]. Major consolidation and maintenance works are being performed across the whole CERN's accelerator chain, in order to prepare the LHC to restart at higher energy, in 2015. The injector chain shall resume earlier, in mid-14.

We report about the on-going vacuum-controls projects. Some of them concern the renovation of the controls of certain machines; others are associated with the consolidations of the vacuum systems of LHC and its injectors; and a few are completely new installations.

Due to the wide age-span of the existing vacuum installations, there is a mix of design philosophies and of control-equipment generations. The renovations and the novel projects offer an opportunity to improve the uniformity and efficiency of vacuum controls by: reducing the number of equipment versions with similar functionality; identifying, naming, labeling, and documenting all pieces of equipment; homogenizing the control architectures, while converging to a common software framework.

## ARCHITECTURES

In the 90's, the vacuum controls of the PS-Complex and SPS were renovated to an architecture based on CPUs in VME crates (Versa Module European), called DSC (Device Stub Controller); these were remotely accessible via Ethernet on a graphical interface, firstly based on X-Windows, and later on Java "Working-Sets".

The DSC collected data through an RS232/X25 interface: either directly, from industrial controllers equipped with RS232; or from the custom-made front-ends, through G64 concentrators.

In the years 2000, the SPS was upgraded to a PLC (Programmable Logic Controller)-based architecture with Siemens®-S7 series. It was followed by the new LHC and by the partial renovation of the PS-Complex. The PLC accesses field equipment: directly on a fieldbus (Profibus®) or via remote-IO stations (Siemens ET200).

The Supervisory Control And Data Acquisition (SCADA) is built on PVSS® (Siemens WinCC-OA); its Data Servers (PVSS-DS) talk with the PLCs via Ethernet. Both PLC & SCADA follow the UNICOS framework [2].

Table 1: Instrument Count for the PS & AD Renovations

| | VGR/P | VGI | VPG | VPS | VPI | VPC | VVS | TOT |
|---|---|---|---|---|---|---|---|---|
| PS | 86 | | | 117 | 156 | | 13 | 372 |
| AD | 72 | 19 | 16 | 100 | 65 | 6 | 15 | 293 |

## PS & AD RENOVATIONS

The Proton Synchrotron (PS) is part of the LHC injector chain; the Antiproton Decelerator (AD) produces low-energy antiprotons for the study of antimatter. Within the CERN accelerator chain, only the PS and AD kept their legacy control system until today.

During LS1, a significant amount of maintenance and consolidation will be performed on both PS & AD machines, in order to improve their reliability for the next 20 years. This is an occasion for renovating their vacuum control system, by propagating the PLC/PVSS architecture, bringing the hardware & software to the level of the other machines, and thus to enforce standardization.

The TPG300® controllers, for Pirani/Penning gauges (VGR/P), need simply to have their communication card replaced from RS232 to Profibus. The old custom controllers for Bayard-Alpert gauges (VGI) cannot be upgraded and will be replaced by modern Volotek®, already with a Profibus interface.

The old ion-pump (VPI) controllers will be replaced by recent ones, accessed over standard remote-IO stations. The sublimation-pump (VPS) controllers will be kept, connected through newly-designed remote-IO stations. That will also be the case for the cryogenic-pumps (VPC).

In AD, the outdated pumping-group (VPG) controllers will be eliminated or replaced by standard models. Profibus will be available for the mobile groups, along the AD ring. In the PS there will be no renovation of VPG.

The valve (VVS) controllers will be upgraded, and controlled directly from the PLC local-IO.

The power distribution to the racks will be re-dimensioned and standardized. The most critical components (such as PLC, valve & interlock controllers, and some pumping-groups) will be backed-up by UPS at AD and by Diesel-generator in PS.

A power line will be pulled throughout the AD ring, for the heaters mounted on the VPI electrical feed-through, to prevent humidity and oxidation.

All cable numbers and connections will be identified, in order to revise the electrical documentation; in particular, the logic and wiring of the interlocks (for pumps, valves, and client systems) will be checked and updated. Once the new controls are fully commissioned, the old components will be definitely removed and discarded.

Like for the other machines in the CERN accelerator complex, Working-Sets will be replaced by PVSS. New SCADA and PLC applications will be developed for the specific controls of VPS and VPC.

ISBN 978-3-95450-139-7

## CPS CONSOLIDATIONS

Apart from the renovations of PS & AD, maintenance and consolidation works will be applied to the other machines in the PS-Complex. This is also the occasion to replace the damaged cables.

### *LINAC2*

The first 3 pumping groups, near the source, had already been upgraded to connect to Profibus; the remaining 6, on the accelerating cavities, will also become remotely accessible, without requiring the presence in the rack room to be operated.

### *PS Booster*

Renovated a few years ago, the Booster will now have its 43 VPS remotely controlled, like PS & AD. Indeed, never before the VPS had been integrated in the Profibus/PLC architecture of any machine; the remote-IO controller and associated software will be developed for LS1.

### *Profibus for Mobile*

In LEIR, a temporary Profibus network will be installed, to provide remote access to mobile devices, such as the "bake-out" controllers. The installation of a Profibus network for mobile devices, in PS, PSB, and TLs (Transfer Lines), was initially thought for the LS1; this was postponed due to budgetary constraints.

### *TLs*

All devices in the Transfer Lines are presently controlled by the PLCs of LINAC2, PS & PSB. When LINAC4 will replace LINAC2, the controls should all be concentrated on the PLC of PSB. Technically possible in LS1, this was also postponed.

## SPS CONSOLIDATIONS

### *New Sectorization*

Each of the 6 ARCs in the SPS is divided in only 2 vacuum sectors, of about 400 m. To reduce the pumping time for these long volumes, they will both be split into 2. Therefore, the 12 new sectors will need to be equipped with extra instruments, cables, and controllers.

Due to budgetary and manpower limitations, the installation of cables and instruments will not take place during LS1. However, the control racks are being prepared in advance: the new controllers will be installed; the 4 racks, corresponding to the 4 new sectors per Sextant, will be re-arranged, together with their internal cables.

In point1 (BA1), additional sectors will be created around a Kicker and a Dump, isolating them from leaks in the vicinity. Apart from the usual extra instruments, a special pendulum valve has to be integrated.

In point5 (BA5) two sector valves, which have been in local mode for some time, will be integrated in the control system, therefore inducing the creation of 2 new sectors. Also in BA5, new gauges will be added to assess the performance of Carbon coating on beam pipe in magnets.

### *TT10 Consolidation*

The injection line into the SPS will have its instruments renovated. While the control of the gauges and valves was already of the modern flavor, new cables and new standard controllers are needed for the VPIs. The 4 racks will be re-arranged by vacuum sector.

### *Racks Re-organization*

With the successive addition of new equipment along the years, re-structuring the SPS racks topology became necessary. We will start with the ones already concerned by current activities: TT10 (4 racks), and the ARCs (6x4).

Besides, the full 15 racks in BA5, and their internal cabling, will also be organized by sector. The controllers will thus be better recognizable and accessible; with some slots reserved for expansion on each rack, it will be easier to add new equipment to any sector, without breaking the order. This prototype work will inspire the evaluation of feasibility and effort needed for the rest of the machine.

### *Damaged Cables*

The radiation accumulated by the cables in the tunnel progressively degrades their characteristics, eventually destroying them. As part of a campaign of cyclic renovation, all the cables on the right of point1 (TS1+) will be replaced; likewise for the TDC2/TCC2 target area.

In the transfer line to the North Area (TT20), only the damaged cables will be replaced. In left of point1 (TS1-), the number of problems was steadily increasing; all cables will be replaced. A patch-panel rack at the bottom of the pit will be used to split the segment in the tunnel from the one up to the racks.

## LHC CONSOLIDATIONS

Several LHC subsystems will require new instruments or consolidations. NEG cartridges will be added to increase pumping speed on Inner Triplets, Stand Alone Magnets, collimator areas, VAX areas, and ADT in IP4; the corresponding power supplies will be integrated in the control system, to perform the activations remotely.

New instruments are also needed for NEG pilot-sectors and electron-cloud diagnosis. Remotely monitored thermocouples will be installed near the collimators (IP3, 7).

Some 570 new control cables are required all around the LHC. The preparation and check of the cabling requests has been done. The advancement of the ongoing cabling campaign determines the schedule for the equipment installation and commissioning.

### *Pumping Groups*

One additional fixed pumping group (VPGF) will be installed at each extremity of the QRL, in order to provide pumping redundancy; this implies 16 new controllers and the associated cables.

Given the number of chambers opened during LS1, extra pumping capacity will be needed: 75 old mobile pumping groups (VPGM) will be renewed, and their controllers upgraded with touch-panels & Profibus interface.



ISBN 978-3-95450-139-7

New PLC software will be deployed for all VPGF controllers, based on a state machine sequencer, and incorporating auto-restart & auto-venting.

### *Bypass Valves*

For the ARC magnets, each insulation vacuum sector should be connectable to an adjacent sector, to use its pumping as backup if needed. Therefore, every 1 out of 2 vacuum barriers must have a bypass valve (total of 7 per LHC ARC). Although the cabling was ready, those valves were not initially mounted in 3/8 LHC sectors. They will now be installed and integrated in the control system.

### *New Interlocks*

For earlier closure, the beam sector valves at the ARC extremities will trigger on a pressure rise on Q12/Q13 instead of Q7; this requires 32 new gauge pairs VGR/P and the associated cables and controllers.

On the other hand, a re-organization of the VPI interlocks around IP3 & IP7 has been postponed.

### *Mobile Equipment*

New bake-out controller racks were recently produced (20+25), with additional software functionalities [3].

The amount of mobile units (pumping-groups & bake-out racks), with predefined Profibus addresses, has been increasing. As the number of possible addresses is limited, they will have to be re-distributed; the definition of device-sets per machine might become mandatory.

The temporary connections, of mobile devices to the Profibus network in the tunnel, do not always respect the basic rules of linear topology and line termination. To avoid the degradation or loss of communication, often arising in crowded zones, a consolidation of the network is essential, starting with fixed connection boxes to avoid star-points. The training of the users is a crucial point.

### *R2E*

The level of radiation expected from the collimation system at IP7 will certainly induce perturbations on standard electronics. Therefore, all vacuum controls equipment in UJ76 will be moved into a more protected zone, further away from the accelerator: 27 racks will be relocated; 282 cables must be extended from 300 to 500 m, using patch-panels. Special care must be taken with the handling, and routing into the racks, of such a large quantity of cables & connectors [4].

Moreover, the vacuum in the ARCs is measured by active gauges (with local electronics), subject to radiation. In order to better understand their tolerance, irradiation tests are being prepared. In parallel, a new and more accurate active gauge is under evaluation; it will also be irradiated to evaluate its expected life time.

## NEW PROJECTS

### *HIE-ISOLDE*

Like ISOLDE before, its extension will also be based on the UNICOS framework; it will be installed in 2014-18. The main challenge will be the cryogenic modules, where beam & insulation vacuums are merged.

### *LINAC4*

The new linear accelerator, at the start of the LHC injector chain, will be installed in 2013-15. The control architecture is the same as LHC, with some specific developments, like the hydrogen gas-injection for the source.

### *NA62*

The renovation of the experimental line and detectors will be performed during 2014. The main challenge is the mix of turbo-molecular pumps and large cryogenic-pumps, for very wide beam pipes & detector chambers.

### *nTOF*

In 2014, during the renovation of this short secondary beam experimental line, the vacuum controls will be integrated within the PS-Complex PLC/SCADA.

Table 2: Instrument Count for the new Projects

| | VGR/P | VPP | TMP | VPI/VPC | NEG/EH/TT | VVS | TOT |
|---|---|---|---|---|---|---|---|
| **HIE-IS** | 68+5 | 10 | 28 | **VPC**: 1 | | 20 | 132 |
| **LIN4** | 40 | 19 | 17 | **VPI**: 50 | **NEG**: 8 | 8 | 142 |
| **NA62** | 48 | 19 | 8 | **VPC**: 8 | **EH/TT**: 14 | 5 | 102 |
| **nTOF** | 12 | 5 | | | | 2 | 19 |

## QUALITY MANAGEMENT

In order to improve the efficiency of the services provided by the controls team, to vacuum experts and to accelerator operators, a Quality Management Plan [5] is being put into place. Several methods & tools have been defined, and are progressively being implemented & used.

### *Naming*

The vacuum controls architecture and equipment have a history rich of a few decades; several versions of the same equipment, from different generations, may coexist even in the same machine. Inspired from the naming usage in the LHC, and in conformity with the "LHC QA Definition", we have set the coding rules for vacuum controls equipment, independently of the machine.

### *VTL*

To optimize resources and time, the traceability of problems, requests, repairs, and other actions, has been put into place. The Vacuum-controls Tracking Log (VTL) provides a means to: follow the dates of request, execution and finish; assign a level of urgency; record the solutions implemented; highlight the response delay, the engaged resources and the volume of handled issues.

ISBN 978-3-95450-139-7

### *MTF*

Extensive effort is being put on the identification and labeling of each individual device, with a coded "part-identifier". Together with the registration in a central database (MTF), this will allow to trace its history and thus: optimize future repairs; organize preventive maintenance actions; manage versions, spares and obsolescence.

### *EDMS*

An important ongoing effort is the gathering of old documents and the centralization of information on architectures, procedures, equipment parameters & settings, in an Oracle database (EDMS). It will allow keeping information up-to-date, coherent, sharable, and reliable.

### *Layout*

The topology of all instruments & control devices will be described in Layout-DB, the source for control systems configuration and for on-line operational information.

## SCADA DEVELOPMENTS

The SCADA applications for vacuum have been under significant evolution, regarding their ergonomics, configurability and standardization [6]:

- simplified and normalized presentation of information;
- coherent functionalities & menus, across all machines;
- automatic scripts, instead of fastidious manual actions;
- enhanced tools, for data analysis and interventions.

The access to the interlock thresholds stored in the TPG has been improved; all TPGs on a given PLC can now be seen simultaneously; the tracking of parameters was extended to machines beyond the LHC.

The main SCADA panel of each machine shows now the status of every sector valve, represented by color-coded circles. The renovated Replay function animates the past evolution of synoptics and bar-graphs, with the purpose of analysis and education.

Other tools, for data-mining & data-analysis, are currently being studied, in order to be operational in 2015.

The PLC Remote-Reset is integrated in the SCADA.

### *Notifications*

The mail/SMS notifications have been enhanced, driven by the increasing amount and variety of pre-defined Warnings. The user configurations can now be imported from an external table, in a normalized format.

The machine and vacuum operation modes can be taken into account in the generation of a Warning.

### *Archiving*

To avoid saturation of the archives by noisy channels, "archive smoothing" is automatically selected, with adaptive parameters; the archiving being stopped only if smoothing is inefficient; additionally, every night all blocked channels are restarted. After all, if a channel appears too noisy on a trend, a filter may be used to extract its minimum values at a given rate.

### *Versions & UNICOS Convergence*

The PVSS package has been evolving, from ActiveX to QT graphics and from V3.6 to V3.8, on Linux; it will soon go to V3.11, at last fully compatible with Win-7. History archiving, limited to about one year deep, will be moved to an Oracle server, independently maintained.

While preserving the current functionalities, a convergence towards the CERN UNICOS framework is under preparation; new libraries of objects & functions, tailored for vacuum, will be developed for both PLC and SCADA. Having it ready, for Linac4 in 2015, will be the first full-scale experience, before global deployment through the whole accelerator chain during LS2.

## CONCLUSIONS

A large amount of maintenance, consolidation, renovation and optimization works will be performed on the vacuum control systems, during LS1. Overall, this involves controllers for more than 1 500 instruments, modified or manufactured, and then tested, installed & commissioned. The installation of some 3 000 cables had to be defined, and later followed, tested & connected.

Table 3: instrument and cable count for all projects

| | New Instruments | New Cables | Replaced Cables |
|---|---|---|---|
| **PS** | 372 | 365 | 21 |
| **AD** | 293 | 29 | |
| **CPS other** | 49 | 6 | 3 |
| **SPS** | 74 | 229 | 276 |
| **LHC** | 392 | 562 | 8 |
| **R2E LHC** | | 480 | |
| **HIE-ISL** | 132 | 390 | |
| **L4** | 142 | 350 | |
| **NA62** | 102 | 200 | |
| **nTOF** | 19 | 60 | |
| **TOTAL** | **1 575** | **2 671** | **308** |

One of the major challenges will be to have all machines re-commissioned in time for the restart of the LHC and injectors, and ready for operation up to 14 TeV.

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ISBN 978-3-95450-139-7