THE CONTROL SYSTEM OF CERN ACCELERATORS VACUUM [CURRENT STATUS & RECENT IMPROVEMENTS]

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Abstract

The vacuum control system of most of the CERN accelerators is based on Siemens PLCs and on PVSS SCADA. After the transition from the LHC commissioning phase to its regular operation, there has been a number of additions and improvements to the vacuum control system. They were driven by new technical requirements and by feedback from the accelerator operators and vacuum specialists.

New control functions have been implemented in the PLCs; new tools have been developed for the SCADA, while its ergonomics and navigation have been enhanced.

INTRODUCTION

The CERN Accelerator Chain

To minimise the interactions between the accelerating beams and the residual gases, and thus maximise the beam lifetime, the beam pipes of all accelerators must be pumped down to a suitable vacuum level.

The Large Hadron Collider (**LHC**) at CERN is a 27 km proton accelerator-collider, with two separate beam pipes that merge at the interaction points. The static vacuum pressure is of about 10^{-11} mbar; due to beam dynamic effects, it can rise up to 10^{-8} mbar.

In order to achieve high fields for accelerating and guiding the proton beams, superconducting materials are used. Therefore, magnets and RF cavities are operated at temperatures down to 4.5 or 1.9 K; they are fed by a separated cryogenic distribution line (QRL).

For thermal insulation, both the superconducting magnets and the QRL are immersed in vacuum below 10^{-5} mbar, often reaching 10^{-7} mbar. The beam and insulation vacuum systems of the LHC totalise some 109 km.

Feeding the LHC, the Super Proton Synchrotron (**SPS**) and its transfer lines add 16 km of beam pipe vacuum [$10^{-7}..10^{-9}$ mbar]. Going back through the chain, the Proton Synchrotron (**PS**), its Booster (**PSB**) and the Linacs (**L2**, **L3**) add a further 2 km.

Vacuum Gauges

To read pressures from atmospheric down to 1 mbar, simple membrane gauges (**VGM**) are used. Thermal conductivity (or Pirani) gauges (**VGR**) are linear in the range $1..10^{-3}$ mbar. Cold cathode ionisation (or Penning) gauges (**VGP**) reach further down [$10^{-5}..10^{-11}$ mbar].

To cover a wide pressure range, a pair of Pirani and Penning are assembled together and read by common electronics, becoming a "full-range" gauge (**VGF**).

Hot cathode ionisation (Bayard Alpert) gauges (**VGI**) are used in the range $10^{-7}..10^{-12}$ mbar.

Vacuum Pumps

Primary pumps (also called "roughing pumps") are used to evacuate from atmosphere down to 10^{-3} mbar; they are also used as a backing pump for Turbo Molecular pumps (TMP), who are effective in the range $10^{-3}..10^{-10}$ mbar. Often they are both assembled and controlled together as a Pumping Group. If their usage is temporary, they can be are embarked in a mobile trolley (**VPGM**), together with the powering and control electronics. For long-term pumping (**VPGF**), only the pumps and powering circuitry are left close the accelerator, while all the radiation-sensitive electronics is kept in safe areas.

When needed to reach ultra-high, vacuum sputter-ion pumps (**VPI**) are added [$10^{-5}..10^{-11}$ mbar]; as a bonus, their current consumption is a good measurement of the pressure.

Sublimation pumps (**VPS**) are used in the range $10^{-9}..10^{-12}$ mbar. Cryogenic pumps are used in particular cases.

Vacuum Valves

To isolate a pumping group from the pumped volume (vacuum sector), roughing valves are used (**VVR**). Sector gate valves (**VVS**) provide isolation between vacuum sectors, to prevent leak propagation, or to allow for a mechanical intervention. There are also window valves (**VVW**) and fast shutter valves (**VVF**).

Instrument Count in Accelerators Vacuum

All in all, (Table 1) there are more than 6 000 instruments to be controlled and monitored, distributed along 128 km of vacuum, in the range of $10^{-4}..10^{-11}$ mbar. The mobile pumping groups are not counted here; nor are the gauges and valves in the fixed pumping groups.

Table 1: Vacuum Equipment in CERN Accelerators

	L2,L3, PSB,PS	SPS	LHC beam	LHC insul.	other facilities	total
length [km]	2	16	59	50	1	128
log (P [mb])	-7..-10	-7..-9	-8..-11	-5..-7	-4..-10	-4..-11
PLC master	5	8	28		3	44
PLC other	0	10	7		0	17
PLC slave	0	0	100		155	255
VGM	0	0	10	231	0	241
VGR	102	113	428	348	61	1052
VGP	122	128	649	364	66	1329
VGI	28	0	167	0	16	211
VGF	0	13	4	0	0	17
VPGF	7	3	14	179	51	254
VPI	370	1429	825	0	69	2693
VPS	48	0	0	0	0	48
VVS	76	87	305	39	13	520
VVF	0	11	0	0	0	11
VVW	0	5	0	0	0	5

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VACUUM CONTROLS ARCHITECTURE

The CERN accelerator complex has a history rich of several decades; vacuum controls architecture and equipment have been evolving, with the construction of every new accelerator machine and with the availability of new technologies.

Given the different evolution paths of each machine, managed by different entities, and depending on the funding availability, it was not obvious to always enforce homogeneity of architectures, equipment and naming. It is common to find several versions of the same equipment, from different generations, coexisting in the same machine. In order to increase the efficiency in debugging and repairing and to simplify the stock management, a considerable effort is being put into analysing the existing versions of each equipment and selecting only a couple of them, that would comply with most of the requirements.

Stand-alone Locally Operated Vacuum Controls

In the early times, a central control room near the accelerator concentrated all electromechanical actuators and displays; they were directly cabled to the machine and were not accessible from elsewhere.

That is still the case of some experimental facilities around the PS Complex, where the electromechanical equipment has been replaced by electronic front-ends, but continues to be accessed only locally.

VME & X-Windows / JAVA

In the 90's [1,2], the vacuum controls of the PS Complex and SPS were renovated: for each facility, a VME crate (DSC - Device Stub Controller) collected the data through an RS232/X25 interface; either directly, from industrial controllers equipped with a RS232 port (VGR, VGP, TMP), or through G64 concentrators, for custom-made equipment (VVS, VPI, VPS). The DSC was remotely accessible through Ethernet, on Unix workstations running X-Windows and MOTIF as graphical user interface. The pumping groups, however, were kept running in stand-alone mode.

Until the next wave of renovation, this is still the case of the PS Ring, AD (Antiproton Decelerator) and CTF3 (CLIC Test Facility), although with new graphics provided by Java ("Working Sets").

PLC & PVSS

Since 2000, the SPS, then the LHC (Fig. 1) and part of the Complex PS have been upgraded to a PLC-based architecture [3,4], using the Siemens™ S7-400 series. The human-machine interface is a SCADA (Supervisory Control And Data Acquisition), built with PVSS®.

The application software for both PLC and PVSS started to be custom-made by the vacuum group. With time, it included a growing number of building blocks from the UNICOS framework [5].

Geographically limited accelerators or installations are controlled by a single PLC. Wider machines have one PLC at each underground service area (Complex PS: 5, SPS: 7; LHC: 28). Independently of the number of PLCs used, there is only one PVSS Data-Server (DS) per accelerator complex.

The PLCs and the DS communicate through Ethernet in a protected and restricted "Technical Network"; consoles in the "Office Network" can have access limited to monitoring the evolution of vacuum variables.

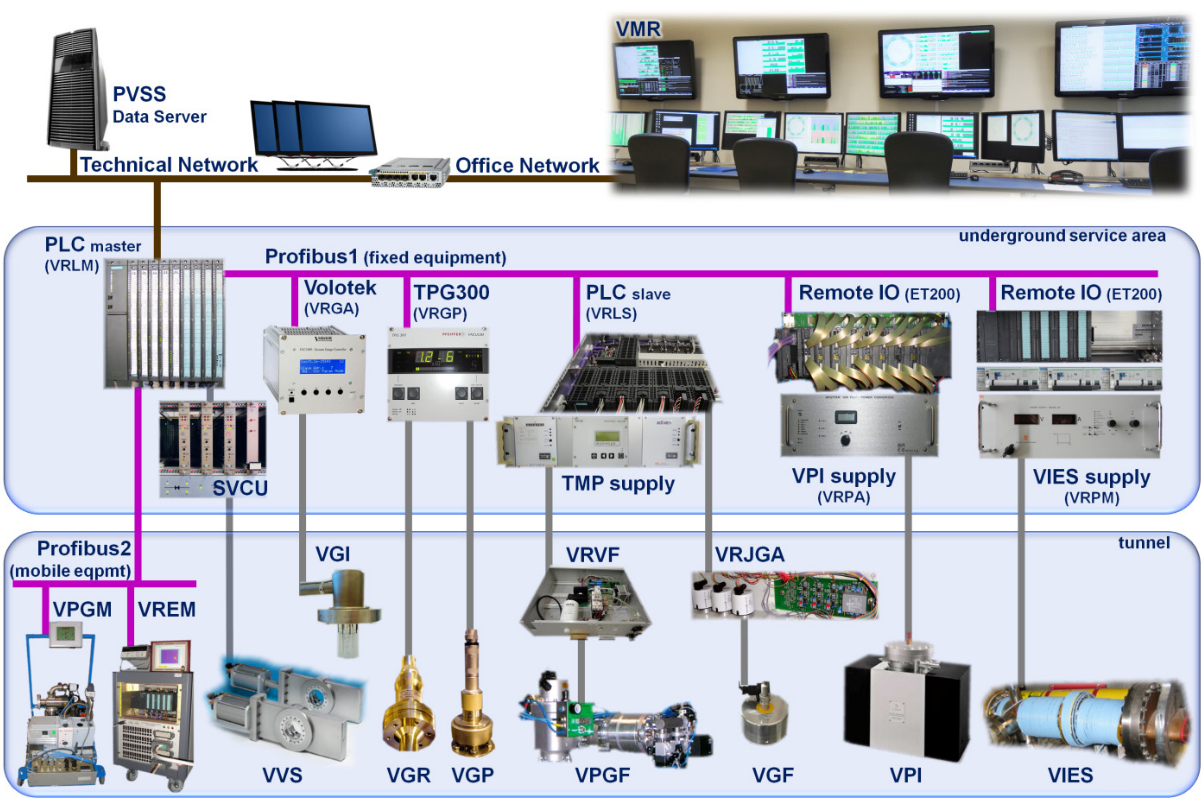

Figure 1: LHC vacuum controls architecture.

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Equipment in the Underground Service Areas

A PLC accesses the field equipment (gauges and pumps) through controllers or power supplies; the modern ones are often intelligent, as they have an embarked microprocessor or other programmable device, like an FPGA; when equipped with the corresponding interface, they can communicate with the PLC via Profibus® (a serial communication link for field equipment); this minimises the complexity and price of cabling and also allows for a wider exchange of information and configuration parameters. This is the case of the controllers for VGI (Volotek), for the VGR and VGP (TPG300), and for the power supplies of the recently added "anti-electron-cloud solenoids" (VIES); also, the fixed pumping groups (VPGF) and their TMP controller are managed by a small "Slave" PLC (S7-300), connected to the "Master" PLC by Profibus.

On the other hand, the controllers for the VVS are directly connected to individual IO channels on the PLC; the power supplies for the VPI are connected to remote-IO stations (Siemens-ET200).

While the PVSS-DS reside on centralised surface buildings, the PLCs, controllers and power supplies are kept in underground service areas, away from the accelerator tunnels where radiation could damage them.

Equipment in the Tunnel

In the accelerator areas where the estimated radiation was considered as acceptably low, and where the distance to a service area was quite large, "active" gauges were installed. These consist of a VGF (pair of VGR+VGP) with its front-end electronics nearby. Individual VGR and VGP ("passive" gauges) that are closer to the radiation-protected areas can be directly accessed by a remote TPG.

A dedicated dynamically-configured Profibus network connects the Master PLC to the "mobile" equipment; although sensitive to radiation, they only come to the tunnel when the machine is shut-down. Examples are the mobile pumping groups (VPGM), managed by another "Slave" PLC (S7-200), and the mobile bake-out stations (**VREM**) handled by an S7-300.

Interlocks, Alarms & Warnings

To restrict potential leaks, if several pressure readings (VGP, VPI) in the same vacuum sector rise above a given threshold, an interlock is sent to the VVS controller; the neighbouring sector valves will then close, confining the vacuum sector. To limit its sensitivity to noise or spurious variations of pressure, this interlock is a voting combination of the relay outputs of TPG and VPI_supply: if a majority of the readings is OK, no interlock is produced. However, if at least one relay is not-OK while the neighbouring valves had been closed for some reason, the valves cannot be opened again until all relays are OK. The details of the voting logic are machine-dependent.

As the automatic closure of the VVS would interfere with the beam circulation, when a pressure interlock is going to close the valves, an interlock is also sent to the beam control system (BIC), in order to previously dump the beam. Conversely, the "beam ON" information from the BIC prevents the manual closure of the VVS.

Hardware interlocks are also sent to the control systems of cryogenics, RF, MKI and MKD, in case of degradation of the respective isolation vacuum.

Devices like the VPI, VGP and VGI may be degraded or even damaged if operated at too high pressure; their controllers have internal protection interlocks to power them off in case their pressure reading rises above a given threshold; for the VGP, the interlock can also be derived from the associated VGR within the same TPG.

Less critical situations, but nevertheless important to other control systems, are sent from PVSS to the LHC Alarms Service (**LASER**), to be handled by the accelerator operators.

Vacuum issues demanding the attention or intervention of an expert generate also an alarm in PVSS, which will send a mail or SMS to the corresponding list of experts.

The PVSS application provides a wide set of visual warnings, in terms of colours and widget animations, to draw the attention of the operators in case of unusual conditions.

Communication with Other Systems

Process status and values are published by PVSS, to the other control systems, through the middleware interfaces **CMW** or **DIP**. Also, PVSS can get data from CMW and DIP. Alarms for the accelerator operators are published to LASER. The corresponding configuration comes from **CCDB** (the Controls Configuration database).

The PVSS own local archives are limited in size, and therefore in time-depth, depending on local disk capacity; therefore, the historical data is periodically sent to a central repository - the **LOGGING** database.

Databases & Software Generation

A set of ORACLE databases contain the information necessary to automatically generate the equipment description for the PLCs and for PVSS.

The **Master DB** contains the parameters common to all the machines. This includes the definition of **equipment types** according to the physical characteristics. In addition, equipment is also classified by **control types**, with a set of attributes required to interface the equipment with the control system. Often, equipment of the same type are controlled in the same way.

The **Machine specific DBs** (LHC DB, SPS DB, CPS DB) contain information about each machine, such as the definition of all vacuum sectors, and the individual attributes of each installed equipment. The information about the geographical distribution of all vacuum equipment is imported from the Layout and Survey databases. A user-friendly Java application (**DB_editor**) allows the manual entering or modification of any individual attribute.

The **DB_export_tool** combines the information from the above data bases and produces the configuration files for both PLC (DataBlocks) and PVSS (DataPoints, CMW and DIP servers, LHC Logging, LASER, etc.).

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NEW FEATURES

PLC

The control of the pumps and valves in a pumping group is the result from a simple logic combination of several status inputs, including pressure levels, together with some timers. After a power failure, some of the status inputs are lost and the group has to be restarted manually. This is particularly annoying if a thunderstorm causes a power cut in a large region of an accelerator.

A palliative solution was implemented, that includes the cyclic memorisation of the status inputs; when the function detects that the power of the group was off and back again, it tries to automatically restart it, taking into account the memorised status inputs.

In parallel, a completely new approach is under development, using the concept of sequential state machine. Here, the outputs of the function depend only on the current state of the machine, not on the input values. The state is the memorised resultant of the sequence of previous states and inputs. At any time it will be easy to restart from the memorised state.

In order to reduce the electron-cloud effects in the beam vacuum, several solenoids have been installed around critical parts of the LHC. A new function was developed to control this new type of equipment and allow the operators to manually pilot their current from PVSS.

To fight unexpected leaks in the insulation vacuum, it became necessary to quickly install a pumping group with the electronics kept in radiation-free zones. The automatic recognition and integration of slave PLCs into the mobile Profibus has been extended for this purpose.

PVSS

In order to improve the ergonomics and efficiency of diagnostics, several improvements were made on the existing PVSS tools. The users can now define and save the full details of their own email/SMS notifications, one by one or globally in a table. Also the historical trends can now be configured and saved by the users. The query for device list has been improved and merged with the query for state/value history, within a given time frame.

To increase security, the PVSS application now starts with user "monitor", who has no rights to manipulate anything. This way, the user ID is not anymore inherited from the current Operating System session. Only when the operator actually needs to perform any action, he will log into PVSS to gain his access rights; after a period of inactivity he will be automatically logged off. This way, we minimise the time a console can remain unattended with a full-rights account.

The values of the thresholds for the interlocks produced by the TPGs can be accessed and modified from PVSS. In times of accelerator study and development, those interlock levels may be changed by the experts. In order to keep track of these modifications, a new tool was developed to automatically back-up of the parameters of all the TPG, every day.

In order to improve the diagnosis of the vacuum systems and the organisation of preventive actions, new panels were created and others were enriched (Fig. 2). The equipment of the PS-Ring and AD, although still on the previous generation of control architecture, is now available for monitoring on PVSS, using CMW data.

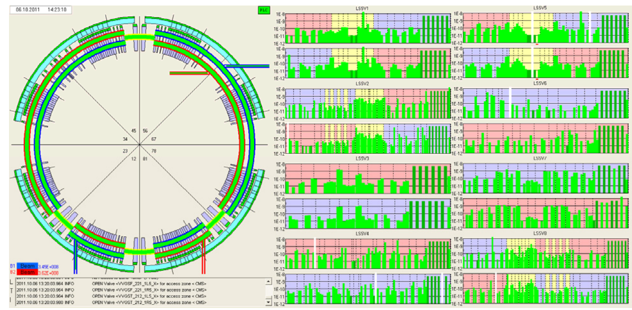

Figure 2: LHC synoptics and pressure bargraphs.

A web server was created, showing PVSS panels that summarise the values and status of the vacuum systems. The function that lists all interlocked valves has been upgraded and exports a list to the web server.

A monitoring room (**VMR**) was set, with 4 stations directly on the technical network and 4 wall-screens running the web summary pages. Soon, all PLCs and DS will be available on **DIAMON**, a tool for remote surveillance and diagnostic of all CERN controls infrastructure.

The PVSS graphical interface for windows clients has been upgraded from the old ActiveX to QT. This finally allows to smoothly move the PVSS servers from Windows to Linux, and also to have client applications on Linux machines.

CONCLUSIONS

New functions have been implemented in the PLC and PVSS. The ergonomics and configurability of the PVSS application have been enhanced.

There is still a long way ahead, regarding the homogenisation of equipment and controls across machines, the convergence towards UNICOS, and the tools for tracking of events, interventions and repairs.

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