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LHC VACUUM SUPERVISORY APPLICATION FOR RUN 3

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Abstract

The LHC Vacuum Supervisory Control and Data Acquisition application has been upgraded to fulfil the new requirements of Long Shutdown 2 and Run 3.

The number of datapoint elements has been increased from 700k to 1.5M, which constitutes a challenge in terms of scalability. The new configuration of pumping station control hardware has led to an increase in the number of permanently connected PLCs – from 150 to almost 300. A new concept has been developed and deployed, in which the PLC configuration is updated online. The goals were to automate, and to speed up periodic updates of the control system. Integrating of the wireless mobile equipment had led to the acquisition of expertise in dealing with temporary connections and dynamic insertion of device representation in the synoptic.

Other new features include: the introduction of an innovative remote control and representation in synoptic panel of hardware interlocks, the development of a pre-configured notification system, and the integration of asset management into the user interface.

VACUUM SYSTEMS

The Large Hadron Collider (LHC) has two types of vacuum systems:

- The beam vacuum system, which reaches ultra-high vacuum (below 1×10^{-9} mbar).
- The insulation vacuum system, used for thermal insulation of cryogenic components, and which reaches high vacuum (below 1×10^{-5} mbar).

Both systems are divided into sectors delimited by vacuum valves or windows. Vacuum sectors will reduce or entirely prevent the propagation of sudden pressure increases. They also allow for independent venting and interventions.

The beam vacuum system of the LHC has 321 sectors. Only a few sectors have pumping group stations [1] permanently installed. For most sectors, pumping group stations – and sometimes, bake-out cabinets [2] – are temporarily installed during installation or interventions. Pumping group stations achieve high vacuum, after which bake-out cycles decrease the outgassing rate of the vacuum vessel and activate the NEG thin-film coatings. Finally, the permanently installed pumps are started. These include, for example – ion pumps. In addition, every sector has a full set of vacuum gauges.

The insulation vacuum system of the LHC has 235 sectors. These sectors have pumping group stations [1] and vacuum gauges permanently installed.

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Table 1: List of Remote-controlled Instruments

Type	System	Count
Sector Valves	Beam	324
Sector Valves	Insulation	68
Fixed Pumping Groups	Beam	10
Fixed Pumping Groups	Insulation	193
Ion pumps	Beam	906
Pirani Gauges	Beam	455
Pirani Gauges	Insulation	343
Penning Gauges	Beam	803
Penning Gauges	Insulation	343
Ion Gauges	Beam	196
Membrane Gauges	Insulation	237

Table 1 lists the individual quantities of remote-controlled vacuum instruments in the LHC.

HARDWARE ARCHITECTURE

The automation layer of the vacuum control hardware architecture is PLC-based. Figure 1 shows the hardware architecture.

PLCs and controllers are installed in radiation-free areas of the LHC's underground, while the radiation-tolerant measuring cards [3], for gauges, are installed in the tunnel – close to the instruments. Table 2 lists the individual quantities of PLCs, controllers, measuring cards and hardware interlocks installed in the LHC.

Table 2: List of Controllers

Type	System	Count
PLCs	Beam	40
PLCs	Insulation	253
PLCs for mobiles	Beam/Insul.	350
Commercial controllers	Beam/Insul.	654
Valve controllers	Beam	324
Radiation tolerant cards	Beam/Insul.	881
Hardware Interlocks	Beam	282
Hardware Interlocks for Cryogenics	Insulation	539

After a successful Run 2, the LHC entered into Long Shutdown 2 (LS2). This will have lasted from the end of 2018, to the beginning of 2021.

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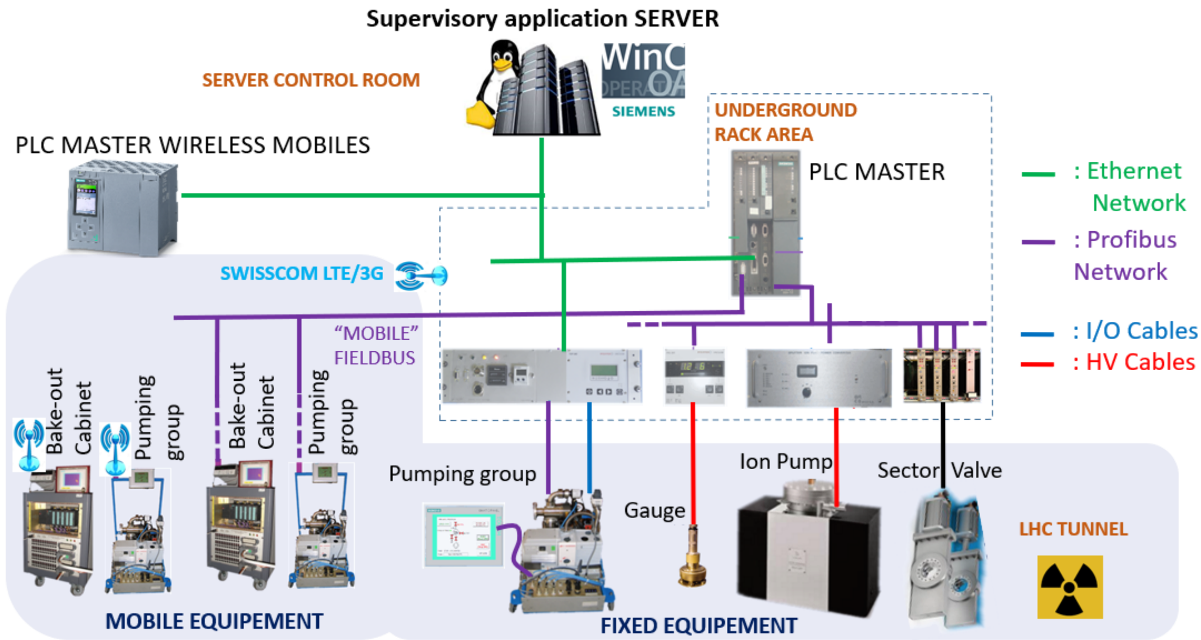

Figure 1: Control hardware architecture.

The following hardware has been upgraded during Long Shutdown 2:

- The permanently installed pumping group controllers (120 models of S7-300, to be replaced with 219 models of S7-1200)
- The insulation vacuum gauges and PLC interlocks (120 models of S7-300, to be replaced with 34 models of S7-1500)
- Mobile pumping groups and bake-out cabinets have been fitted with a 3G/LTE communication solution (55 units).
- New, radiation-tolerant measuring cards (881 units) have been installed for membrane, Pirani and Penning gauges.

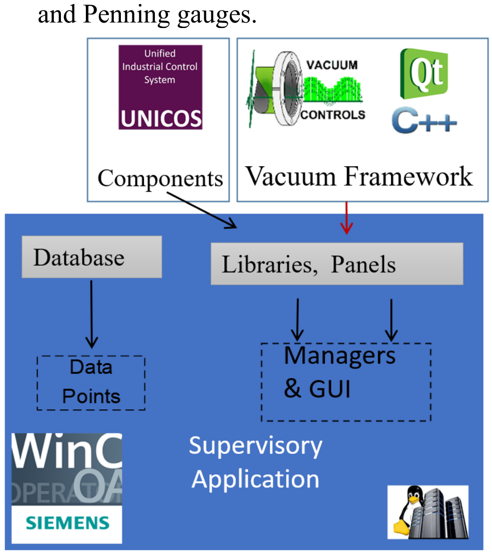

Figure 2: The supervisory application and its components.

THE SUPERVISORY APPLICATION

The Supervisory Control and Data Acquisition of the LHC vacuum system is based on a commercial product: WinCC OA™ by Siemens™. The Figure 2 shows the application components: managers, drivers and libraries. These come from either WinCC OA™ native components, or from CERN standard frameworks such as UNICOS [4], JCOP [5], and the Vacuum Framework [6].

The Vacuum Framework (libraries, panels, and components) customises the application to facilitate vacuum devices and features required for operating the LHC vacuum system.

Proof of Scalability

During the period of Long Shutdown 2, the vacuum supervisory application of the LHC had seen successful growth on an unprecedented scale. The number of data points has increased from 700k to 1.5M due to:

- Integration of 3G/LTE communication solution.
- Integration of new, highly parameterised controllers such as the Agilent™ Ion pump controller.
- Increase of device number, vacuum sectors number and layout complexity.
- Increase of PLC connections, from 150(before Long Shutdown 2) to 290.

DEVELOPMENT OF NEW DEVICE TYPES

Three major control types have been completely refactored (pumping group, ion pump and rough to high vacuum gauge).

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Pumping Group Device Type

A pumping group station is, at minimum, composed of a primary pump and a valve. Depending on the subtype, it can contain a turbo-molecular pump, four additional valves, one or two gauges, an integrated bakeout system, a heated exhaust system, etc. The process is controlled by a PLC, which also manages the interlocks.

The pumping group can be either permanently installed, or temporarily connected to the vacuum vessel (the so-called mobile pumping group). Mobile pumping groups are remote-controlled – either through a Profibus network deployed during the LHC installation in the 2000s, or through the new 3G/LTE communication solution [7].

Altogether, it represents a very large number of subtypes due to all the possible combinations. The development guideline was to standardise the behaviour of the device representation in the synoptic panel and the layout of the device details panel. For all the temporary (mobile) or permanently installed pumping group in the LHC accelerator, a single device type (set of libraries) has been developed.

Process specifications did not change since LHC Run 2. There were, however, significant changes to pumping group control. During LHC Run 2, every instrument (pumps, valves, gauges, etc.) had been controlled individually, and the pumping group had been managed globally, by a process. This allowed the switching of instruments to manual operation, and to drive them independently. As a result of the pumping group controller upgrade, the control becomes global-only, without the possibility of switching individual instruments to manual operation.

At first, development of the supervisory device libraries started in absence of new specifications. Indeed, the instrument itself had not changed; therefore, new specifications had not been requested. As mentioned above, however, the pumping group control method was very different. Choices regarding the new behaviour and standardisation had to prioritise speed over consensus, considering the strict deadline for first deployment.

The first deployment – even though it had allowed for perfect remote control of the pumping groups – was not a success. Mainly due the lack of status information in the synoptic panel, which confuse an operator who had been accustomed to the previous behaviour. A new version must be developed – this time with proper specifications, approved by the operators responsible. The next development and deployment fixed all the issues.

The 3G/LTE communication mobile pumping group is managed by the same device type as the permanently installed pumping group. A new dynamically built synoptic panel has been developed [8] and deployed. The synoptic library inserts or removes the widget representation of the mobile device changing dynamically the length and organisation of the synoptic panel according to the device connection state. The first deployment of the new, dynamically built synoptic panel experienced some issues. The rebuild and display of the synoptic takes a couple of seconds, which is acceptable in normal conditions. Unfortunately, however, the application had suffered continuous disconnection and re-connection cycles, resulting in the synoptic rebuilding all the time. This issue has been fixed by, first, invalidating the device (with a blue colour animation), then introducing a ten-minute timeout, before finally removing the device representation and rebuilding the synoptic.

New Strategy for Pumping Group Updates

Concerning the new hardware, each pumping group has its own PLC controller. This means 219 PLCs that may require updating during LHC Shutdowns and Technical Stops.

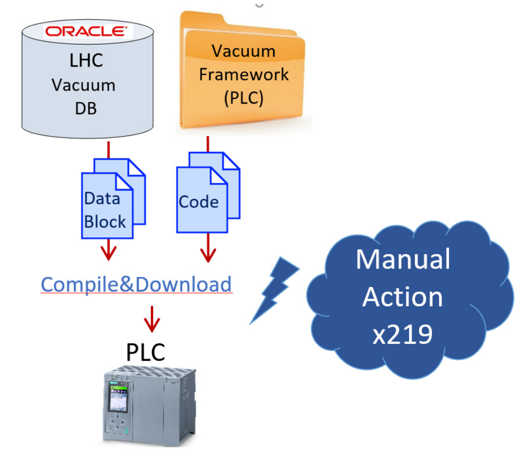

Figure 3: PLC update procedure, following the old/standard strategy.

The update describes in Figure 3, following the standard procedure (as was common before the new strategy) would have taken a very long time. 219 compilations and downloads - each performed manually - usually undertaken for the trivial purpose of changing equipment names or process parameters. Furthermore, this procedure also requires that pumping groups be vented and stopped.

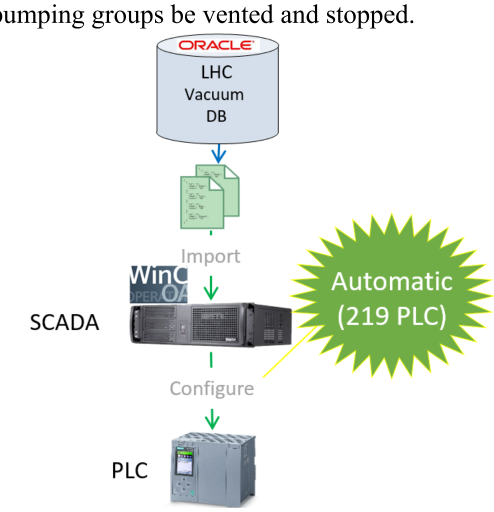

Figure 4: New strategy update procedure.

The new strategy delegates the update of parameters and names (defined in a database) to the supervisory application - making this procedure automatic.

As shown in Figure 4, the configuration step (i.e., the updating of names and parameters coming from the LHC

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vacuum database) is included in the supervisory application update. This is the most common type of update required during Technical Stops. Technical Stops are already short (three-to-four days long), and the time allotted to the control software update is even shorter (half a day). The much faster update and the suppression of manual intervention errors are two obvious advantages. In addition, this procedure does not require for pumping to be stopped, nor does it interrupt the remote control and logging - also very important points.

Updates of the PLC code baseline still require a standard update procedure, but such intervention is rarely scheduled during Technical Stops.

New Ion Pump Controller and Sector Valve Interlock Animation

The ion pump controller measures the current of the power supply. This current is a function of the pressure in the vacuum vessel. The controller is therefore used to provide hardware interlocks to the sector valves with ion pump pressure level thresholds. The new ion pump controllers, installed during Long Shutdown 2, compliment a complete communication interface with remote control of all the parameters and access to all the statuses, including parameters and statuses of the interlock outputs.

To make use of this information, a new animated interlock hardware widget has been developed. Hardware interlock widgets are represented in the synoptic by an arrow pointing in the direction of the target valve. The arrow is represented either in green (no interlock) or in purple (valve interlocked). Sources of the interlock can be changed with the new remote control from one ion pump to another. As shown in Figure 5, the operator can now change the interlock schema on-the-fly and shift the interlock source from a faulty ion pump, to an intact one, and so maintain the level of protection even when a component of the interlock schema fails. This is not such a rare occurence in a vacuum system as large as the LHC's.

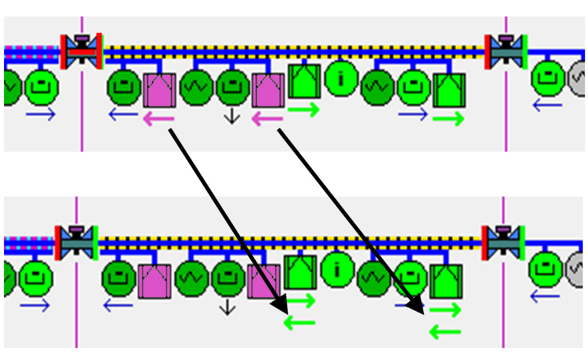

Figure 5: Hardware interlock animation in the synoptic.

I/O Gauge Device Type

Measuring and control cards for I/O gauge are installed in the arcs of the LHC tunnel (for both insulation and beam vacuum). Anticipating increased levels of radiation in the tunnel, the cards have been replaced with a radiation-resistance version. The software framework team took the opportunity to develop a new unified device type for all I/O gauges with a thorough protection scheme.

The Penning gauge is an on/off vacuum gauge to measure pressure ranges between $1x10^{-5}$ and $1x10^{-11}$ mbar. If this gauge were switched on or operated at pressures above approximatively $1x10^{-5}$ mbar - it may be damaged, or at least see its lifetime reduced. To avoid such damage, the gauge is protected either by the controller – or, in case of an I/O gauge – by the PLC. With the new I/O gauge device type, the protection schema has default parameters that can be changed on-the-fly from the supervisory application.

Figure 6 shows all of the protection parameters:

- "Protection Source Gauge": the third-party gauge used to protect the Penning gauge. This is the standard protection scheme that interlock/switch-off the Penning gauge in case of high pressure.
- "Self Protection OFF Threshold": same as above, but the source is the Penning gauge itself. It does not replace the above protection – it acts as a redundancy.
- "Self Protected Mode Threshold": above this pressure threshold, the gauge is switched on for only 16 seconds (duration required for a valid measurement) every 8 minutes. This advanced protection behaviour increases the lifetime of the Penning gauge.

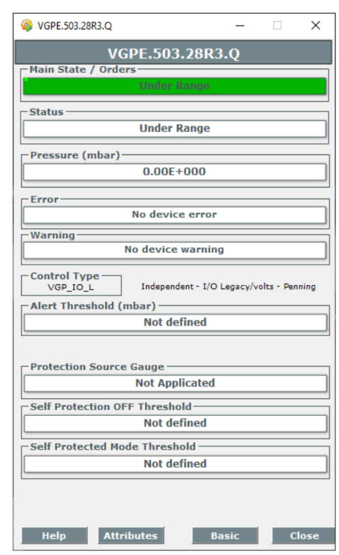

Figure 6: Details panel of an I/O Penning gauge.

NEW NOTIFICATION SYSTEM

The notification system sends e-mail/SMS message according to its criteria. The notification system already existed before Long Shutdown 2. The first version was working well and had already been used on a large scale, but it required advanced user skills and quite a long time to configure parameter criteria.

The new system offers predefined criteria according to the vacuum sector state. The default available modes are:

- Operation beam vacuum: the criteria are based on sector valve positions and the high vacuum gauge pressure value (threshold $1x10^{-7}$ mbar)

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- Operation insulation vacuum: the criteria are based on the cryogenic alarm signal and rough vacuum gauge pressure value (threshold $1x10^{-3}$ mbar)
- On work/intervention: the criteria are based on the sector valve position and pumping group state (not pumping or disconnected)
- Bakeout/NEG Activation: the criteria are based on the sector valve position and pumping group states (not pumping or disconnected), the Bakeout controller state, and the gauge pressure value (threshold $1x10^{-2}$ mbar).

Additional predefined modes and their criteria can be easily defined on-the-fly by the software engineer in charge of the application, simply by adding ASCII text parameters in the supervisory application resources and configuration file. This file is parsed by the notification library during initialisation of the supervisory application client session.

ASSET MANAGEMENT

A functionality to directly manage assets [9] has been deployed to the supervisory application. It requires up-to-date synchronisation of the functional position names between the vacuum database and the CERN Enterprise Asset Management database. It offers an interface from the widget menu to create maintenance or repair requests. This functionality saves a lot of time and encourages proper equipment asset management. It has been largely used by the vacuum operators during the Long Shutdown period.

CONCLUSION

The Vacuum Supervisory application is one of the biggest industrial control applications at CERN with 1.5 million data points, more than 290 PLCs for fixed equipment, and more than 250 PLCs for mobile equipment. The main concern of the application upgrade has been device type standardisation. The layout changes for LHC Run 3 have been properly integrated in the supervisory application with significant changes in more than 40 vacuum sectors. The migration of the new controllers has been successfully integrated, taking the opportunity to increase functionality.

The new features and developments have increased the protection of the vacuum system, reduced effort required for its operation and monitoring, and improved diagnostic capability.

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