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STATUS OF VACUUM CONTROL SYSTEM UPGRADE OF ALPI ACCELERATOR

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Abstract

The vacuum system of ALPI (Acceleratore Lineare Per Ioni) accelerator at LNL (Laboratori Nazionali di Legnaro), including around 40 pumping groups, was installed in the '90s. The control and supervision systems, composed by about 14 control Racks, were developed in the same period by an external company, which produced custom solutions for the HW and SW parts. Control devices are based on custom PLCs, while the supervision system is developed in C and C#. The communication network is composed of multiple levels from serial standard to Ethernet passing true different devices to collect the data. The obsolescence of the hardware, the rigid system infrastructure, the deficit of spares parts and the lack of external support, impose a complete renovation of the vacuum system and relative controls. In 2022 the legacy high level control system part was substituted with a new one developed in EPICS (Experimental Physics and Industrial Control System) and CSS (Control System Studio). After that, we started the renovation of the HW part with the installation and integration of two new flexible and configurable low level control system racks running on a Siemens PLC and exploiting serial server to control the renewed pumping groups and pressure gauges. The plan for the next years is to replace the legacy hardware with new one retrieving spare parts, provide service continuity, improve PLC software and extend the EPICS control system with new features. This paper describes the adopted strategy and the upgrade status.

ARCHITECTURE OF THE LEGACY SYSTEM

The ALPI accelerator is the superconducting linac of the LNL, it is composed of 22 cryostats which were installed in the '90s together with their ancillary systems [1–4]. Most of the original hardware of the vacuum system, which is based on magnetic bearing turbomolecular pumps, have been maintained up to now and is still running. The control and supervision systems was deployed in the same years by a contractor company (TELEMA Computers), which fully developed dedicated HW and SW solutions from the field level up to the communication network and the HMI (Human Machine Interface).

The control infrastructure consists of three main parts: the vacuum controller, the collector and the supervisor. The controller represents the hardware mounted in the 14 racks placed along the accelerator. Each rack, also named VCS (Vacuum Control System) rack, can control the three pumping groups of a couple of cryostats and the diagnostic box between them (see Fig. 1). It is operable locally or remotely from the console. VCS rack is made up of: vacuum instrumentation (vacuometers and pump controllers); a custom serial multiplexer (MUX) and two crates containing ad-hoc microprocessor control boards called PLC (Programmable Logic Controller). Both MUX and PLC are based on Zilog Z80 microprocessor. The MUX collects the information from vacuometers and pump controllers, and forwards a subset of those data over a RS485 4-wires line. The two PLCs manage the valves and pumps actuation, implements the Machine Protection System (MPS) procedures, and manages high level procedures. The first named "Power Additional" controls the pumps, the valves connected to the pumping groups and the beam line; while the second "Additional" takes care of the valves connecting the cryostats to the centralized lines used for forevacuum, He and N2 inlet procedures. Both type of PLCs receive and send information over an RS-485 4-wires line, which is separate by the one for MUXs.

Figure 1: One of the TELEMA racks mounted in ALPI.

Each RS-485 serial networks for PLCs and MUXs extends allong a section of the accelerator (low and high energy), so a total of 4 RS-485 networks are present. Two Windows PC (one for PLCs and one for MUXs) act as collector servers, receiving the data transmitted over the serial lines and forwarding them on the ethernet network up to the main console in the control room. The serial to ethernet conversion and

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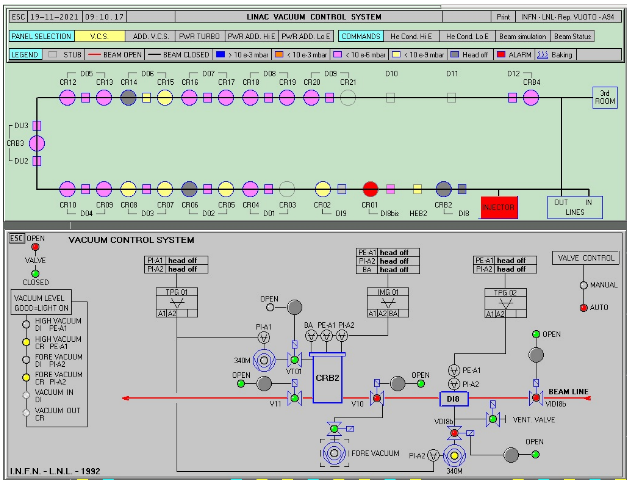

Figure 2: ALPI GUI. VCS page of a specific controller.

polling requests to the VCS are performed by an H8S card. The servers include a simple supervisor to configure the communications for the data exchange and show the collected data in a basic shape.

The Windows PC, used as console, executes the HMI application written in C/C#, which take care of: communication with the servers; coordination of high level functionalities; display the received data organized on the accelerator layout; give access to pages dedicated to specific VCS, instrument and pump, trend chart, system configurations Fig. 2.

At LNL other VCSs, latest than the one used fop ALPI, are used to control vacuum system of beam lines and of the superconfucting RFQ (Radio Frequency Quadrupole) named PIAVE (Positive Ion Accelerator for Very Low velocity ions). Those VCs are based on the same control architecture with some HW and SW differences.

LIMITS AND OBSOLESCENCE OF THE LEGACY SYSTEM

As exposed, the vacuum control system architecture is rigid due to the specific interfaces between the HW parts, which for example doesn't allow to modify the turbomolecular pump model. The limit of the processor memory doesn't allow large SW extensions and the firmware modification require invasive intervention on the HW. After about 30 years from the installation, the lack of spare parts is a major problem to guarantee service continuity to the system. The electronic components for MUX and PLC, as well the H8S board and the models of the turbomecular pump are discontinuated and in house stocks are terminated in some cases.

In addition to that, at the end of 2021 the TELEMA company closed its business interrupting maintenance and upgrade of HW and SW. The available documentation and source code were not sufficiently detailed to take care of the system with internal resourced which don't have knowledge of such dated instruments.

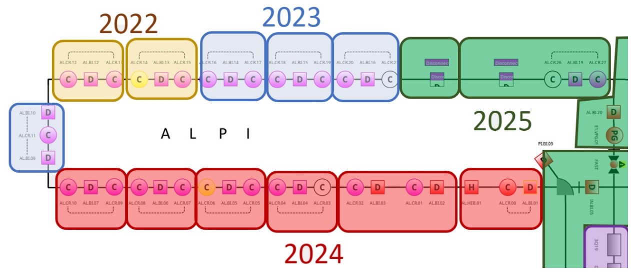

Figure 3: The Vacuum system upgrade plan for ALPI.

THE UPGRADE STRATEGY

The critical situation of the vacuum system can't be overcome without consider vacuum and control system together in the renovation process including the replacement of non-maintainable vacuum components and the complete substitution of the control parts (HW and SW); also keep the the full know-how internally become a essential requirement.

The available resources and the required effort impose to spread the HW replacement over several year (see Fig. 3), which means having old and new system running together. Due to non-maintainability of the high level SW and the critical point of serial/Ethernet collectors in the second half of 2021 the upgrade road map [2] was rewed as follow:

- substitution of the high level software in C/C#, with an EPICS based control system and removal of the server PCs [3];
- substitution of the VCS racks with new ones based on industrial standards and vacuum components replacement [5];
- recover precious spare parts from the upgraded systems to guaranty the operation of the remaining old ones.

The first step allow us to dismiss the high level SW part and some critical hardware, gain a system more robust and easier to maintain and improve. The RS-485 lines are maintained, while a MOXA serial server is used as link to the Ethernet network. The new EPICS IOC managing all the communication task and high level functionalities is deployed on a Virtual Machine (VM) hosted by the main control server, while the updated console PC runs only the HMI developed in CSS (Control System Studios).

The development of the new VCS goes in parallel and starts from a review of the VCS rack recently designed to control the vacuum systems along the new beam lines related to the SPES project (Selective Production of Exotic Species) which is under construction at LNL. The result is a common platform applicable in every part of the LNL accelerator complex. The core of the system consist of a SIEMENS S7-1500 PLC and a 15" touch panel, which are highly available on the market and long time supported by the producer. Moreover the industrial standards adopted and the wide spreads SIEMENS platform guarantees a large base of possible supplier for the software parts if needed.

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Table 1: Table with the Possible Line Configurations

Category	Configuration
ALPI-PIAVE	1 Cryostat, 2 Diagnostics 2 Cryostats, 1 Diagnostic 2 Cryostats, 2 Diagnostics
Consecutive Trasnport lines	1 Volume 2 Volumes 3 Volumes
Special Transport Lines	Cross section Two non-consecutive volumes Merge Fork
MUX Cross lines	from 5 to 15 connections

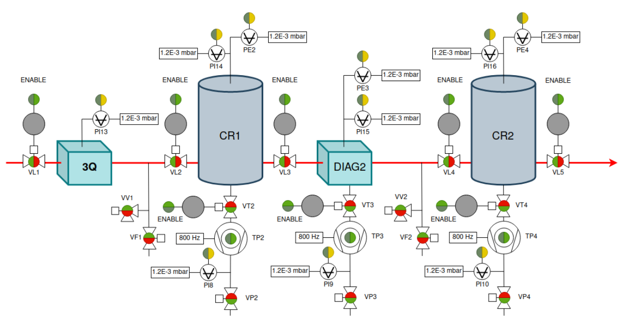

Figure 4: Configuration A21: 2 Cryostats and 1 Diagnostic.

THE NEW ARCHITECTURE

The HW platform of the new VCS is defined considering all the use case present or which will be installed in the next future, where the case of ALPI is the most demanding in terms of I/O. The VCS is intended to be highly configurable both in terms of beam line layout and device models (see Table 1 and Fig. 4). All the possible configurations, and communications with different devices types, are software managed by the local PLC and HMI. The hardware and software design of the new VCS were originally developed by external contractor to control a common straight vacuum line with a maximum of 2 consecutive vacuum sections, but the internal know how about the system allow us to expand it as follow.

The hardware platform is conceptually different from the original one, which foresees the exchange of modular macro parts in case of fault, instead the new design, composed by commercial parts disposed in an accessible way, allows to perform limited interventions with the help of self diagnostic to simplify the research of faulty elements. To enhance the system reliability the PLC and the monitoring equipment are power supplied by UPS line and dry contact are preferred for critical signals such as vacuum thresholds.

The new VCSs use LAN interfaces to communicate together, while standard LAN/serial converters are used to communicate with controlled devices (vacuum pumps, controllers and more) allowing to support several brand and models and to include new devices in the future. VCS racks also include dry contact interfaces for compatibility with the previous systems during transition phase.

Table 2: Controlled Items and Their Maximum Number

Item type	Max N
Vacuum Meters	6
PP (Primary Pumps)	6
TP (Turbomolecolar Pumps)	6
EP (Entrapment Pumps)	6
VL (Beam Line Valves)	5
VP (TP Outlet Valves)	6
VT (TP Inlet Valves)	6
VE (Entrapment Pump Inlet Valves)	6
VF (Fore-Vacuum Valves)	3
VV (Venting Valves)	3
PE (Penning Sensors)	4
PI (Pirani Sensors)	20

The EPICS supervisor communicates with the PLC using the *S7nodave* module, through a LAN interface. On each rack there is a 15" touch panel with an HMI for local operations. The touch panel is remotely accessible to give an additional way to control the system or execute commands which are not foreseen from the EPICS HMI.

THE VCS SW PROGRAM

The development of the PLC and HMI SW began in 2014 [6] with the production of the first prototype of VCS rack. Some years later, a second prototype was commissioned, and in 2019 the first version of VCS rack for the SPES project was completed by an external supplier. From that time SW developments were managed internally.

As for the HW, our choice was to have only one SW version able to satisfy all the foreseen application. A major overhaul started in late 2021 as consequence of the HW review. The first release was deployed in 2 VCS installed in ALPI during the summer 2022. It keeps the described device interfaces, increments the maximum device number (see Table 2) to match all the configurations and introduces a set of new features. At the same time, code modularity was increased allowing the contribution of external supplier to the development of specific communication interfaces.

To optimize the number of DI/DO modules, each acquisition channel can have a different meaning depending on the selected configuration. Most IOs share the same meaning between all the configurations others differ. The map associating a channel to its meaning in the PLC changes based on the chosen configuration category.

Even if the vacuum plants can have a multitude of possible combination, the versioned SW projects for the VCS are only 2, the "Official" which is the one deployed online and the "Test-Bench" version used for new development. When a new system is put in operation the used version is simply noted on a log file. The new SW is intended to be always applicable, as long as the correct configurations are re-entered.

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Figure 5: VCS Rack installed in ALPI.

The PLC implements a dedicated state machine to guide the operator through the configuration steps: selecting the configuration, indicating which components are present and which not and how these are connected. During the procedure the SW detects and blocks inconsistent input, while the HMI provides an interactive view of the layout.

The implementation of the remaining configurations, device combination and procedures required a new deep reorganization of the PLC and HMI code, which is still ongoing and aim to get a SW more modular, easier to maintain and improve.

STATUS

During this year two VCS racks was installed in ALPI and two are expected to be installed before the restart of the accelerator (see Fig. 5). The upgrade of the vacuum system of 2 cryostats including intervention on vacuum, electrical and control part with the VCS substitution take about 2 weeks. To set up the VCS vacuum instrumentation and control take from 1 day to 1 week, mainly due to HW or communications issues. In these years other four VCS racks were put into operations on SPES beam lines.

CONCLUSION AND NEXT STEPS

After about a decade from the first prototype, thanks to the boost provided from SPES project and ALPI application, with a continuous grown at each review, the VCS rack is now a consolidated platform for the vacuum system of the LNL, constituting a key point for the definition of the new installation and renovation strategies of the entire LNL accelerator complex, which will include a total of about 50 racks. To achieve the final goal several steps are still needed, here we reports the major :

- Update the communication within adjacent racks or other systems;
- Upgrade the EPICS integration and the high level functionalities;
- Complete all the expected configuration;
- SW migration from TIA V15.1 to the most recent version;
- Define and adopt a strategy to keep versioning of the configuration in use in each VCS rack;
- Define a strategy to handle small HW differences between the PLC of different VCS (e.g. due to different device version);
- Define a strategy to keep updated the SW version of the VCSs.

REFERENCES

[1] L. Ziomi *et al.*, "The Vacum System of the Superconducting Linac ot the ALPI project", LNL, Legnaro, Italy, Rep. LNL-INFN(REP)-047/91, 1990, pp. 250.

[2] C. Roncolato *et al.*, "Status of the Vacuum System for ALPI/PIAVE section and Upgrading Plan", LNL, Legnaro,Italy, Rep. INFN-LNL-259, 2020.

[3] G. Savarese *et al.*, "Vacuum Control System Upgrade for ALPI Accelerator", in *Proc. IPAC'22*, Bangkok, Thailand, Jun. 2022, pp. 744–746. doi:10.18429/JACoW-IPAC2022-MOPOMS045

[4] R. Pengo *et al.*, "A Heavy Ion Superconducting Linear Post-Accelerator Called ALPI", in *Proc. EPAC'90*, Nice, France, Jun. 1990, pp. 43–46.

[5] G. Savarese *et al.*, "First installation of the upgraded vacuum control system for ALPI accelerator", presented at the IPAC'23, Venice, Italy, May 2023, paper MOPL130, unpublished.

[6] L. Antoniazzi *et al.*, "Status Report of the New Vacuum System for the 8pLP Experimental Line", LNL, Legnaro, Italy, Rep. INFN-LNL-236, 2014.