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THE LINAC4 VACUUM CONTROL SYSTEM

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Abstract

Linac4 is 160 MeV H- linear accelerator replacing Linac2 as the first injector to the CERN accelerator complex, which culminates with the Large Hadron Collider. This new Linac will increase the beam brightness by a factor of two.

The vacuum installation consists of 235 remotely controlled pumps, valves and gauges. These instruments are either controlled individually or driven by pumping stations and gas injection processes. Valves and pumps are interlocked according to gauge pressure levels and pump statuses. The vacuum control system communicates with the beam interlock system, the ion source electronics and the Radio Frequency control system, through cabled digital and analog signals.

The vacuum control system is based on commercial Programmable Logical Controllers (Siemens PLCs) and a Supervisory Control And Data Acquisition application (Siemens SCADA: WINCC OA). This paper describes the control architecture and process, and reports on the control requirements and the implemented solutions.

INTRODUCTION

CERN, the European Organization for Nuclear Research, has built a new linear accelerator called Linac4. Linear accelerators are the first stage of the Large Hadron Collider (LHC) injector complex. The Linac4 is intended to replace Linac2 that is in operation since 1978, and will accelerate H− ions up to 160 MeV.

Linac4 is 90 m long machine composed of 11 vacuum sectors. This sectorisation reduces the effort of the commissioning and limits the impact of leaks or mechanical interventions. More than 230 remotely controlled instruments are used to achieve a high vacuum level all along the Linac4 line. The vacuum level depends on the sector: at the source it is limited by gas injections and reaches 10^{-6} mbar; the sector of the radiofrequency quadrupole (RFQ) reaches 10^{-9} mbar; and the pressure of other sectors is between 10^{-7} and 10^{-8} mbar. The remotely controlled vacuum instruments include pumps, gauges, valves…

The vacuum control system is based on the LHC vacuum control architecture [1], but differs on some aspects: from circular to linear accelerator, specifications change; the hardware interlock system is slightly different; a new type of logic for fixed pumping groups and a specific control process for gas injection have been developed.

HARDWARE ARCHITECTURE

The hardware architecture is a three-layer control system: field vacuum instruments are driven by the controller layer composed of commercial and in-house designed electronic units; the automation layer is based on Siemens™ Programmable Logic Controller (PLC); the supervisory layer is a data server running WinCC-OA™ application. The hardware architecture is illustrated by the Figure 1.

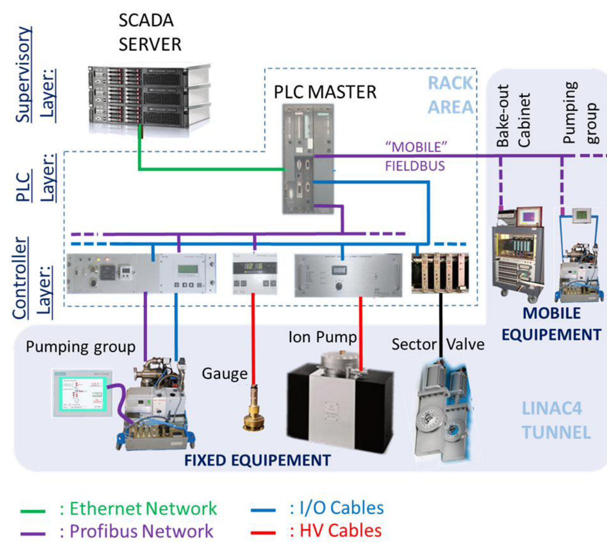

Figure 1: Vacuum Control Hardware Architecture.

Sector Valve Interlock System

The vacuum controls of Linac4 have a hardware interlock system to prevent the propagation of a pressure increase and to protect beam instruments. Sector valve control crates are connected to the Beam Interlock System, in the case of a sector valve closing, the beam is stopped.

The sector valves are interlocked by relays from gauge controllers or from ion pump controllers. The ion pumps are preferred because they are less sensitive to pressure spikes and so reduce the number of false interlocks and therefore of unnecessary beam stops.

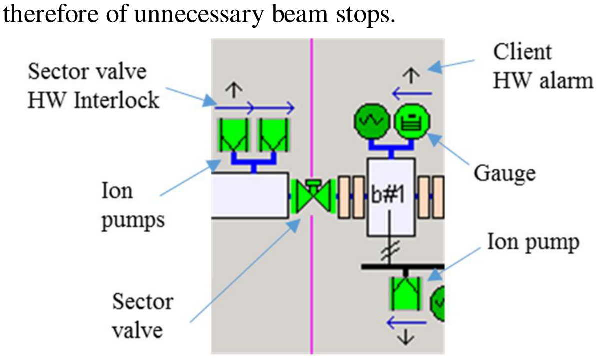

Figure 2: Supervisory panel with instrument widgets and illustration of hardware interlocks.

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Figure 2 shows a sector valve, surrounded by three ion pumps and one gauge interlocking it. On the left, two horizontal arrows pointing to the right illustrate the source interlock coming from left sector. On the right of the sector valve, only one ion pump is available, the second source is a gauge. In Figure 2 there are four sources of interlocks, this number may vary from 3 to 4; it is referred later in this document as $N_{ItlSource}$.

The resulting interlock signal for each sector valve is produced by a small crate according to the following logic: sector valve is open-enable if $N_{ItlSource}$ sources are OK; sector valve is interlocked (close order) if $[N_{ItlSource} - 1]$ sources are BAD.

In addition, a preventive interlock signal forwards valve close orders to the next and previous sectors.

This logic avoids non-relevant valves interlocks and beam stops, while also assures a good level of machine protection.

Client Hardware Alarms

The vacuum control system provides pressure level hardware alarms to protect the beam source, the radio-frequency instruments and the magnets. They are interlocked by hardwired alarms using gauge and ion pump controller relays as sources. The logic depends on the client and is achieved by "multiplexor" crates designed originally for the LHC injectors.

AUTOMATION LAYER

The main PLC is a Siemens S7-400; it controls beam line gauges, sector valves and HV pumps. The main PLC has remote I/O stations installed close to the controllers, to reduce cabling cost. The control of fixed pumping groups, gas injection system and mobile equipment is delegated to slave PLCs. The Linac4 vacuum automation layer is described by Figure 3.

Fixed Equipment

The controllers for vacuum gauges and for pumping stations are interfaced with a Profibus-DP network for "fixed" equipment. Ion pump controllers, valves controllers and other instruments are driven by remote I/O stations. All electronic devices are protected from ionising radiation generated by Linac4 beam; i.e. the fixed equipment controllers are installed in the radiation free rack area. The type of instruments in Linac4 pumping groups differs from LHC pumping groups [2]; the primary pumps are Scroll pumps instead of rotary vane pumps; the gauges are active with embedded electronics instead of passive gauges. However in order to share spare parts and standardize maintenance and intervention, same PLC and local crates as LHC have been used. The crates fit to Linac4 pumping group specifications with the installation of cable adaptor boxes and the use of the PLC crate spare I/O.

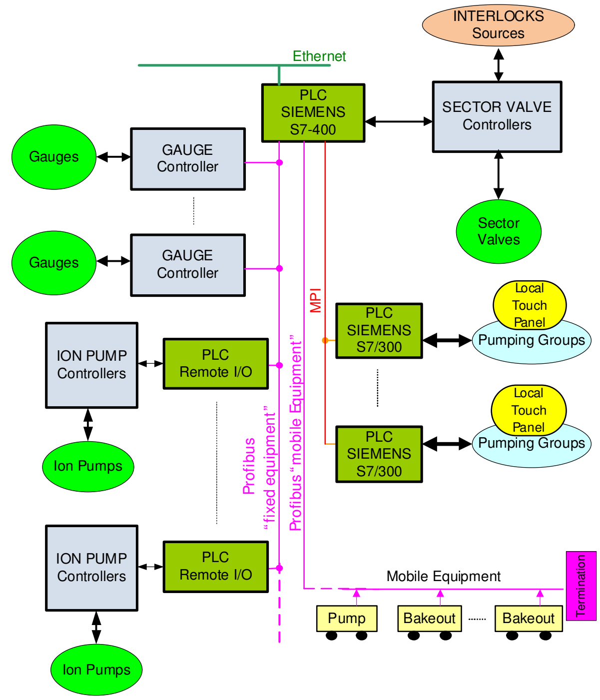

Figure 3: Automation architecture.

Mobile Equipment

Mobile instruments and their controllers are temporarily installed in the tunnel for vacuum installation and interventions. Only cables and connectors remain in radiation area during beam operation. The fieldbus used for mobile equipment is the Profibus-DP network. Once physically connected, the mobile pumping groups or bake-out cabinets are controlled by the supervisory application through the Master PLC that manage a handshake protocol and auto-reconnection in case of power cut or any other fieldbus interruption. It is a basic and robust network very convenient for beam line vacuum interventions. Such interventions have a typical duration of 4-5 days, they can be scheduled through a week-end. The control system offers remote control, diagnostics, data logging and SMS notifications for mobile equipment.

The network for mobile equipment is a serial fieldbus very convenient for small machine but shows some limitations for long lines or when a large number of mobile equipment need to be connected. Fieldbus cables are installed long time before vacuum vessels installation; the layout and specifications may change in the meantime. It is very difficult to define in advance the exact number of sockets and their positions. The serial topology of the Profibus-DP does not support "star" connections. When vacuum operators need to connect several mobile pumping groups or bake-out cabinets to a single socket, an intervention by a fieldbus expert is required to install temporary repeaters or rebuild a local fieldbus.

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Automation Software

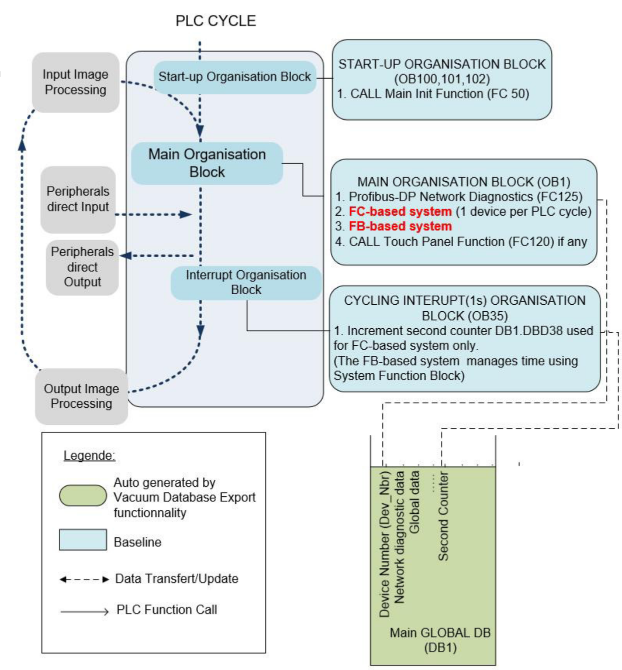

Figure 4: PLC Cycle.

The automation software is based on the one previously developed for the LHC and its injectors. Linac4 vacuum PLC runs two concurrent software systems in same CPU: a FC-based system and FB-Based system. The Figure 4 illustrates the Linac4 PLC cycle and the main organisation blocks.

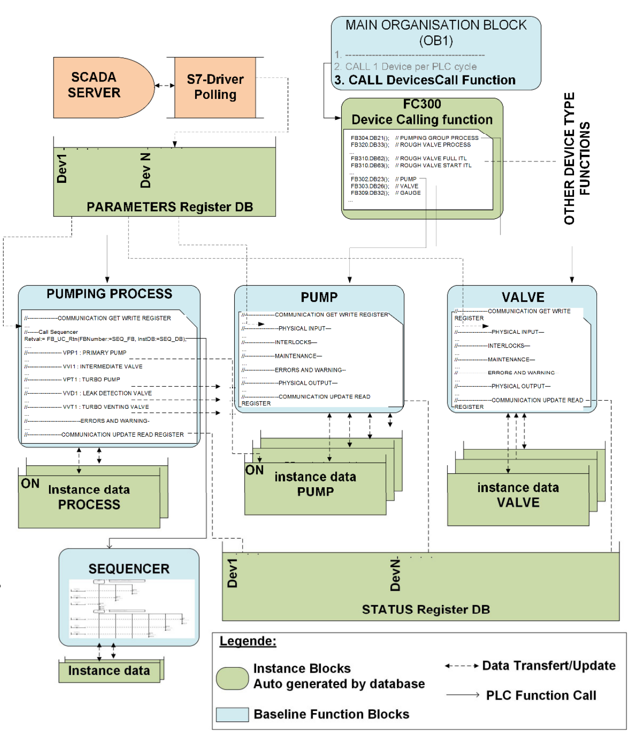

Figure 5: FB-based System.

In 2001, the PLC software started to be developed using Statement List Siemens (STL) language and functions without instantiation (FC-based System). Then, new instruments and new specifications were required, from 2011, new functions have been developed using Structured Text (SCL) language and device oriented Function Block (FB-based System). Figure 5 illustrates the FB-Based system architecture.

LEBT Gas Injection System

One specific development for the vacuum control system of Linac4 is the gas injection system of the Low Energy Beam Transfer (LEBT) tank. This one requires H2 gas density to correct radial size and angle of H- beam. The Figure 6 illustrates the gas injection user interface panel displayed on top of the synoptic panel.

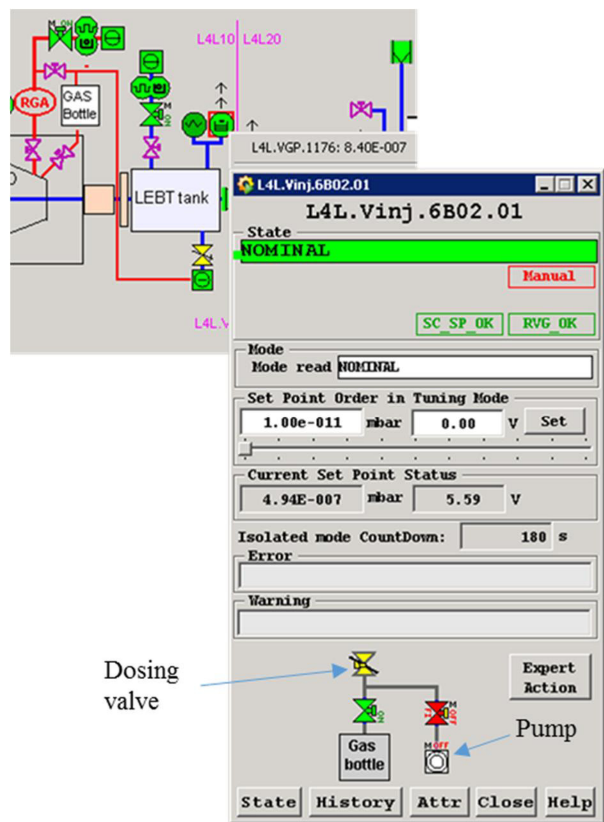

Figure 6: Gas Injection control panel.

The H2 dosing valve is a thermal analogue valve, which is powered by a PLC Analog Output, and that remains opened when not powered.

The "Isolation" mode is the start-up stage of the process, it prevents to inject high load of gas (initial position of the dosing valve is opened). The dosing valve has no position indicator and the reaction time to close the valve is very long (more than 1 minute). The system is protected by a time out in the "Isolated" mode that does not allow any mode transition before the end of 3 minutes count down. The gas injection system regulates the dosing valve according to the sector gauge process value (PV) and an input set point (SP). In "Tuning" mode the regulation starts with a

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very low SP = $1E^{-11}$ mbar, then operator may define a manual SP. In operation the process is changed to "Nominal" mode where the SP is received from the beam control system through PLC Analog Input. Process and mode transition is illustrated by the Figure 7.

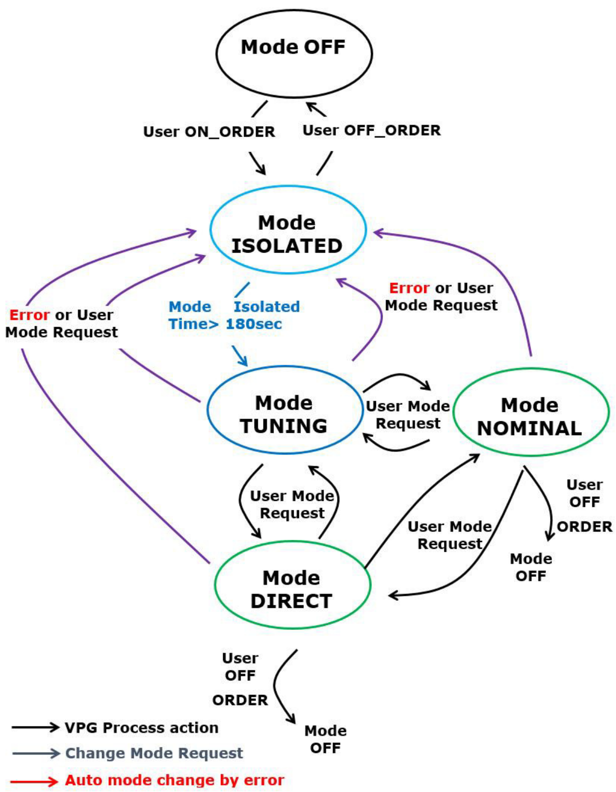

Figure 7: Gas Injection Process.

Database and SCADA

The Linac4 vacuum controls is using the same vacuum software framework as LHC, injector complex and experimental areas [3]. This framework has been updated for Linac4, it integrates gas injection widgets and panels described in previous paragraph *LEBT Gas injection system.*

ISSUES AND CORRECTIVE MEASURES

After the installation of the first dozen of ion pumps and pumping groups, the automatic restart after power cut (frequent event during a machine installation phase) failed, leaving the sector in critical pressure raised situation. The start current of Scroll primary pump was much higher than was foreseen (20 times higher than nominal current instead of the 10 times value used for calculation), the result was a trip of the rack power supply circuit breaker. The power distribution has been upgraded and pump start time are staged by the PLC.

The ultra-high vacuum of the RFQ sector is achieved by four pumping groups (active pumping during operation) and Non Evaporable Getter pumps. After the first vacuum commissioning, the pressure in the RFQ sector suddenly raised to 3mbar and the four pumping groups stopped. The primary pump (Scroll pump) of one pumping group stopped but the safety valve (called "SecuVac") did not close. The result was a venting of the whole sector stopped by the automatic closure of the pumping group top valve. The consequence was a delay of four days in vacuum installation due to the redo of the vacuum commissioning for RFQ sector. The cause was an accidental disconnection of the primary pump on the pump side. The safety valve was not individually controlled but powered by the same cable as the primary pump and so cable disconnection on pump side did not power off the safety valve. As a corrective measure a new cabling design has been defined; the safety valve is now powered through the body of the pump insuring the safety valve is closed when the connector is disconnect even on pump side. From this event, every safety valve installation follows this new cabling convention.

During first in-situ tests and commissioning of Radio-Frequency (RF) instruments, pressure spikes triggered the RF power supply several times. As described in previous paragraph *Client hardware alarms*, hardwired alarms for RF are directly generated by our ion pump controllers. These units have a very poor I/O interface and so post-mortem diagnosis are very limited. The pump current measurement (used to calculate the pressure level) and the pressure alarm trigger level have been in-situ re-calibrated for all the ion pump power supply units. Replacement with new units integrating remotely settable hardware alarm relays is currently being evaluated.

CONCLUSION

The Linac4 is not yet connected to the LHC injectors but the installation of the most critical sectors has been completed. The machine has already run a complete year of beam commissioning without any vacuum controls issues. In autumn 2017 the Linac4 has been integrated in the list of machines monitored and maintained by the vacuum stand-by team, enlarging the Linac4 vacuum control users (previously limited to beam operators and Linac4 vacuum experts) to the whole Vacuum Group. This smooth transition demonstrated the user friendliness of the vacuum control system.

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