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MOBILE PUMPING UNITS FOR PARTICLE FREE BEAM VACUUM

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Abstract

Commissariat à l'Energie Atomique et aux Energies Alternatives (CEA) is in charge of providing cryomodules for European Spallation Source (ESS). This collaboration lead CEA to design, build and provide cryomodules with industrial quality requirements and challenging milestones.

One critical element for cryomodules efficiency is vacuum quality and more specifically lack of particles. To reach this particle free beam vacuum, pumping units were specifically designed build and are still use at CEA Paris-Saclay.

This article will focus on these pumping unit for vacuum and control system point of views.

INTRODUCTION

Context

ESS cryomodules are built in several steps. Most of them are did in clean room to limit particles generation in order to avoid pollution and unwanted interactions with beam. One element to answer to this problematic is a mobile pump unit built by CEA Paris-Saclay vacuum and control teams.

Constraints

The pumping system must answer to following constraints:

- It should be able to pump cavity up to -9mBar,
- It must be outside clean room to avoid particle generation, reliable for permanent use,
- Remotely control by operator in clean room and locally by other operators,
- Mobile from a pumping spot to another,
- Exchangeable and user friendly.

Goals

Control system was designed to be the best assistant of clean room operator and to be forget, so when an operator starts an automatic pumping sequence, he can work without according attention to the system. Another goal of the system is to be safe and reliable. A lot of securities were developed, integrated and tested to prevent any operator error and to protect the pumping unit in case of hardware malfunction.

REQUIREMENTS

Presentation

The set-up needs to allow a leak check down to leak rates of 10^{-10} mbar l/s, cavity assembly and pumping procedures will lead to reach this goal.

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Vacuum Process

The movement of particles in UHV systems has been studied systematically by DESY using an in-vacuum particle counter. Slow pumping process inherit of this study.

Clean Room

Cryomodule assembly is a long and complex process that need specific tools to avoid particle generations. CEA Paris-Saclay clean rooms answer to this requirement with pumping slots providing a safe connection with regular atmospheric pressure environment.

Pumping Slots IRFU DACM main clean room is design and is wide enough to build cryomodules cavity train. Due to the cavity's quantity and different state of each one they often are at different vacuum and clean status. Therefore, pumping slots must be accessible up to six at the same time. Valves and pumps movements are generating particles so pumping units can't be located in a clean environment.

Thanks to sealed connections a cavity inside the clean room can be connected to a pumping unit outside clean area.

Therefore, independent pumping procedures could be start for each cavity.

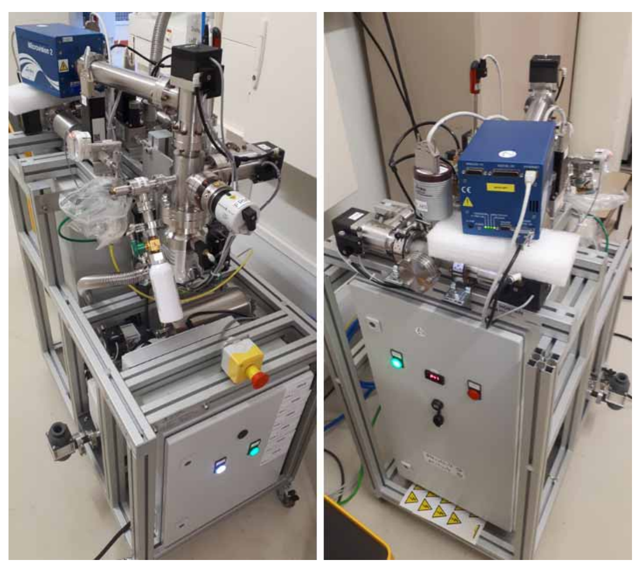

Figure 1: Mobile pumping units.

Mobile Flexibility As mentioned in previous chapter pumping units are connected to pumping slots. CEA Paris-Saclay have height pumping units use for multiple purpose of clean pumping in different locations: three clean rooms and one cryomodule test stand. According to experiments needs they have to be move from a location to another. This is the reason why they are mobile (see Fig. 1).

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When pumping unit must be move few connectors must be unplugged: vacuum, nitrogen, network and electrical. When next pumping slot is reached quick reconnection allows operator to start quickly a new pumping process.

Control Interface

Clean room operators must be focus on cryomodule assembly process so pumping units control interface must be ergonomic and require only few actions with a scalable detail level.

Local-Control Mobile aspect of pumping units require a local control interface to provide system status, automatic procedures and manual commands to operator when pumping unit location change. This is especially true when new position is out of network range for experiments occasional use.

This functionality is granted by local industrial touch panels (see Fig. 2) connectable to pumping unit. There are two screens in use at CEA Paris-Saclay switchable from unit to unit. This small amount of device is explain by few uses for experimental areas not connected to regular network.

Thanks to industrial connectors and associated control architecture operators can connect and disconnect local control interface without any specific action, it will automatically reconnect to the pumping unit and identify it.

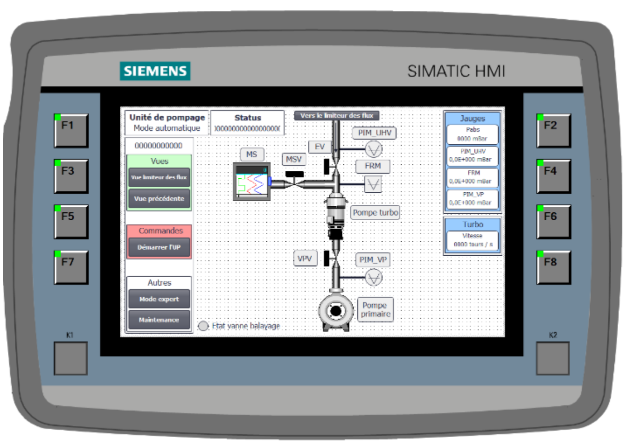

Figure 2: Mobile control interface.

Remote Control Pumping units are mainly connect to regular control system network and allow, through a control interface server, to remotely connect from inside clean room, vacuum workshop and even desktops. This remote control is done with a CEA Paris-Saclay self-develop software call Muscade ©. This control interface provide same interface than local control interfaces but with more functionalities: Residual Gas Analysis (RGA) report can be generate and multiple operator can connect to it remotely and simultaneously with an enhanced security connection.

Mass Spectrometry

Vacuum quality and composition can be check with a RGA device providing one hundred particle mass and enabling fine pollution diagnostic. Therefore, it also could be used for leak check by scanning mass number 4 associated to Helium.

Explicit RGA diagram is the work base of vacuum expert when they are looking for the cause of a contamination or a leak. After connection establish between RGA and mobile pumping unit control system data are displayed in a trend of one hundred columns representing each mass value acquired.

Operator can scroll to have specific pressure value and so precise diagnostic.

Industrial Use

Mobile pumping units are used by CEA agent but also by industrial sub-contractor for cryomodule assembly. They have to be reliable, easily use, interchangeable and with clear diagnostics.

Reliable System Mobile pumping units are industrial device and need reliable, versatile and interactive control system. Programmable Logical Controller (PLC) answers to these requirements, this is why mobile pumping unit control system is PLC based. In addition to these features a high level of diagnostic is mandatory to be able to maintain in a long life-time system that have to be everyday operational.

Exchangeable System Availability of mobile pumping units is mandatory to maintain a smooth process of cryomodule assembly. If a pumping unit is not available because of an internal malfunction another must replace it with minimum possible actions. In order to provide a full exchangeable system every mobile pumping units are similar. Except IP addresses they are mirror from each other's this means that control system must be similar for every units, from hardware to software aspects.

Control system was developed to provide a smooth experience to user: the only thing to do when a group replace another is to define is geographic position through local control interface.

CONTROL ARCHITECTURE

Mobile pumping unit control architecture will be described in following paragraphs, from hardware to Graphic User Interface (GUI).

PLC Based Control System

Control system base technology is PLC and more specifically Siemens solutions. Siemens is widely use at CEA Paris-Saclay because of is reliability, matching local control standards and control team skills.

Hardware In order to be up to date and grant a long time available hardware, we chose Siemens last PLC generation: 1500 references. Central Processing Unit (CPU) 1516 3 PN-DP is connected to four input-output cards: analog input, analog output, digital input and digital output cards. By using different kind of cards we could manage a lot of signals: 0-10V for pressure sensors, 0-24 V or 4-20 mA for valves.

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PLC CPU is also connected by network to one Siemens device mobile panel and non-Siemens hardware like turbo-pump controller and MKS mass spectrometer (see Fig. 3).

Software Standards Developments Siemens PLC based control system leads us to use manufacturer software developing solution called: TIA Portal. By using in a wide range Siemens solutions we previously developed functions for signals conversions, hardware protection and even communication functions with our own developed SCADA Muscade ©. These functions are in our software standard library and are reliable by experience feedbacks and updates.

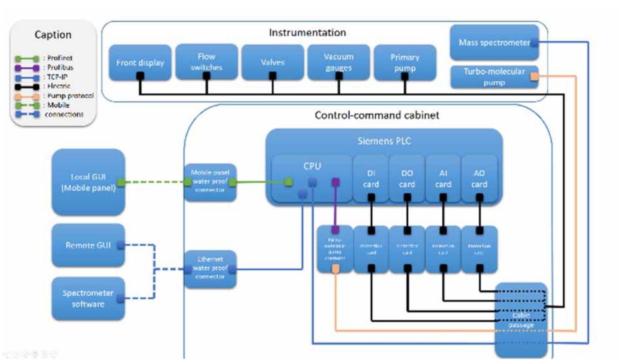

Figure 3: Control architecture.

Software Specifics Developments Specific functions were developed for communication between PLC and mass spectrometer. Therefore, scan commands and mass values can be shared thanks to a network connection.

Automatic Procedures Preliminary pumping, slow pumping to prevent particle generation, leak check and back to automatic pressure is managed by automatic procedures functions developed in correlated development language: Grafcet.

Operator interactions is limited to a start and stop button. Once started, automatic procedure manages itself and can detect and reacts to unexpected behaviors.

Goal is to reduce possible human errors and increase reliability by reducing human actions and increasing automatic hardware diagnostics in a close loop.

Operator Assistance Procedure Additionally to automatic pumping procedure there is an operator assistance procedure to guide operator in cavity pumping, manual operations, non-contamination verification with RGA (see Fig. 4) and generating automatic quality report.

Network Architecture

PLC CPU communication with control systems elements is managed thanks to two hardware layers and three protocols. First network hardware layer is Ethernet and second layer is Siemens wires according to Profibus standards (see Fig. 5).

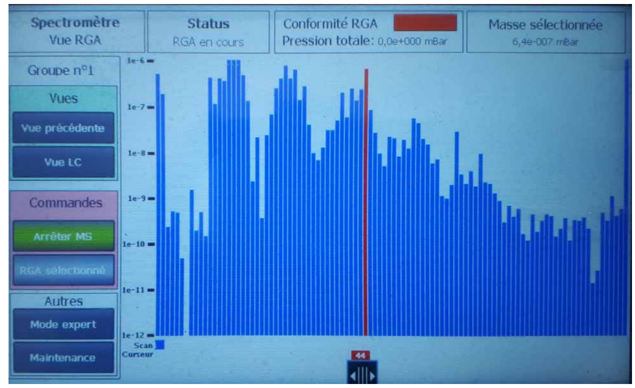

Figure 4: Mass spectrometry results.

Modbus-TCP Ethernet layer is issue as one part for sharing data with mass spectrometer and local SCADA Muscade ©. PLC manages communication for GUI interface via Modbus-TCP and TCP ASCII with mass spectrometer.

Profinet Siemens industrial protocol Profinet enable native and integrated communication between Siemens devices via Ethernet. For mobile pumping units this is use to connect PLC CPU and local control interface known as mobile panel.

Profibus Siemens industrial protocol Profibus enables native and integrated communication between Siemens devices via Profibus cables. For mobile pumping units, this is used to connect PLC CPU and Pfeiffer turbo-pump controller.

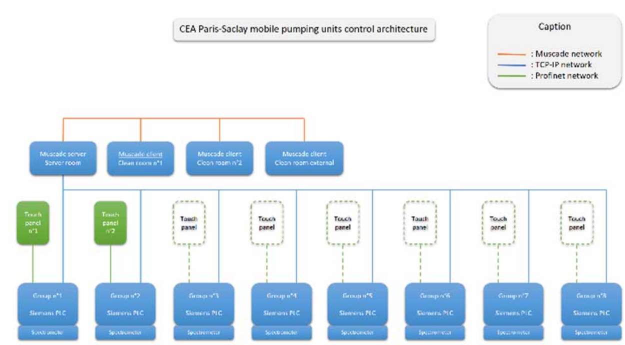

Figure 5: Network architecture.

Graphic User Interface

Main functionalities of GUI are automatic sequences start and stop in operator mode, direct actuator command in expert mode, sensors feedbacks and RGA data display.

Moreover, users can switch from local to remote control without ergonomic changes. That's why ergonomic study started with mobile interface and so touch panels because the constraints are stronger than remote PC screen.

Ergonomic Principles Keep ergonomic principles in both local and remote GUI while taking into account of specific functionalities was a study by itself. This study leads us to define windows structures and color code.

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Windows Structure Was defined according to a simple case: how can an operator hold mobile GUI in both hands and easily control the mobile pumping unit?

We choose to place commands sub-window and important information near operator hands, on left and right of touch screen, to enable with thumbs to start and stop automatic procedures or to switch from a screen to another.

Full control of pumping unit only with two fingers is a success according to user feedbacks.

Color Code Second element of GUI ergonomic is color code. How can an operator easily distinguish area for commands, sensors feedbacks, view navigation or parameters?

Red sub-window will contain sequence start and stop buttons. Sequence button can be pressed only if preliminary conditions are granted thanks to local protections but we must draw operator attention about his actions thanks to a danger color.

Green sub-window enable windows navigation. This color is opposite to commands so no hardware actions will results of touch in this area.

Blue sub-window hold sensors data. Information displayed there are read only.

Eventually white sub-window is dedicated to general parameters.

Local HMI Siemens GUI named “Mobile panel” provides a 7 inch touch screen were must be displayed all previously mentioned data and commands. It was developed within TIA Portal and more specifically WinCC Comfort.

This device is connect to mobile pumping unit trough a specific connector managing power supply and communication.

Remote HMI Muscade© SCADA is a CEA Paris-Saclay homemade software with very convenient functionalities especially for original users: cryogenic experts. For mobile pumping unit clients for clean room, vacuum workshop and even desktop connect to a unique server. View were duplicated from WinCC to AutoCAD and imported in Muscade © thanks to a specific homemade tool.

In addition to local HMI functionalities the remote system can also provide screenshot and timestamped data in a file use for quality report about vacuum status in cavities

RESULTS

Control System

Mobile pumping units and there embedded control system are in use since 2019 and provide full satisfaction to clean room operator and cryomodule tests.

This versatile and embedded control system could be use in a lot of applications type and we are excited to see where the future can drive mobile pumping units in industries and experiments.

Experiments

These tools were developed by CEA Paris-Saclay in order to answer to ESS cryomodule assembly requirements. We will see in next chapters that they reached their goals and so more.

ESS Cryomodules assembly and test by CEA Paris-Saclay teams provide an objective feedback about our height pumping groups use and contribution to ESS collaboration [1-3].

Twenty four cryomodules were built with the help of height mobile pumping units for a total of three hundred thirty six pumping without particle generation and back to atmospheric pressure procedures. Vacuum analysis were done two hundred sixteen times thanks to spectrometer communication with PLC CPU and integration in automatic procedures.

SARAF CEA Paris-Saclay is providing four cryomodules for Soreq particle accelerator using our mobile pumping units.

IJCLab CNRS laboratory IJCLab is using one mobile pumping unit for his own clean room.

CONCLUSION

Mobile pumping units were designed to be a concentrate of functionalities with goal of reliability, user friendly and to be a particle free pumping system.

According to users and experiments feedbacks we can say that this system is a success that provides satisfaction to all initial requirements.

We are excited to see in which other experiments it could be use in the future.

ACKNOWLEDGEMENT

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