Vacuum Controls & Diagnostics

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on behalf of TE / VSC / ICM
TE – Technology Department
VSC – Vacuum, Surfaces & Coatings Group
ICM – Interlocks, Controls & Monitoring Section
Part 1: Field and control layers
- Vacuum Controls architecture
- Gauges & controllers
- Low current measurement
- Pumps & controllers
- Hardware interlocks & alarms
- Example of radiation effects on Vacuum electronics
- Future trends & developments

Part 2: Supervision layer
- SCADA
- WinCC-OA architecture
- Configuration of a large control system
- Vacuum Functionalities
- Applications, servers and networking
- Enterprise Asset Management
Part 1: Field and control layers

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Vacuum controls architecture

Supervision layer

Control layer

Field layer
6000+ vacuum instruments to be controlled and monitored

Along 130 km of vacuum chambers
Pressure range [10^{-4} .. 10^{-12} mbar]

PLCs: 300+

Gauges: 3000

Pumping groups: 250
Ion pumps: 2700

Sector valves: 500
**Vacuum instruments in the LHC tunnel**

**Dispersion Suppressors (<100 Gy/y)**
- Active piezo gauges and local power supplies for pumping groups
- All other components are passive
- Controllers installed in radiation free areas
- Cable length up to 600m

**Long Straight Section (>100 Gy/y)**
- Only passive components except local power supplies for pumping groups (w/o turbo controller)
- Controllers installed in radiation free areas
- Cable length up to 400m

**ARC (<10 Gy/y)**
- Active gauges (Piezo, Pirani, Penning)
- Local power supplies for pumping groups (w/ radiation tolerant turbo-controller)
- PLCs installed in radiation free areas
- Cable length up to 1km
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  - Example of radiation effects on Vacuum electronics
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Membrane gauge (Piezo-resistive)

- Thin silicon crystal layer used as a membrane
- Membrane deformation induces piezo-resistive effect
- Measurement from 1 .. 2000 mbar; ~ 10% uncertainty

- Piezo-resistive elements constitute a full Wheatstone bridge
- Bridge supplied by a constant current (wire resistor)
- \( V_D \) (\( \sim \)mV) is a measure of the membrane deformation
- Up to 3 gauges per controller; needs calibration
- 0-10V, 4-20 mA, protection relays

\[
V_D = I_{EX} \cdot \Delta R
\]  
\[
\Delta R = f(P)
\]  
\[
V_{OUT} = Ad \cdot V_{MEAS}
\]
Thermal conductivity gauge (Pirani)

- Thin tungsten filament heated to constant temperature (~ 120 °C)
- Based on heat conductivity through a gas; gas dependent
- Pressure measurement from $10^3 .. 10^{-4}$ mbar; ~ 30% uncertainty
- The filament constitutes one element of a Wheatstone bridge
- The bridge is self compensated by an amplifier in feedback loop
- $V_{OUT}$ (~V) is a measure of the pressure
- Up to 2 gauges per controller; needs calibration
- Profibus DP connection; 0-10V; protection relays

$$V_{OUT} = \sqrt{2R_f \epsilon \left( p_0 + \frac{p}{1 + gp} \right)}$$

$\epsilon$: sensitivity [W/mbar]
$p_0$: lower limit of the measuring range [mbar]
$g$: constant depending of the geometry

$R_f \sim$ 130 to 150 Ω
Strong effect of $R_{wire}$ (long cable)
High E field (3 kV); B field (0.1 T)
Gas discharge
$I^+ = K.p^m, m \sim 1$; current from $10^{-6}$.. $10^{-12}$ A
Pressure measurement from $10^{-5}$.. $10^{-11}$ mbar; ~ 50% uncertainty
Controller has a HV power supply and electrometer
Leakage simulates higher pressure
Up to 2 Penning gauges per controller; factory calibrated
Profibus DP connection; 0-10V; protection relays
Used as interlock source; robust

**Diagram:**

- Penning Gauge
- Penning Conditioning circuit
- $V_{OUT} = R_f \cdot (I_{ion} + I_{leak})$
- $I_{leak} \ll I_{ion}$
Active gauges (Piezo, Pirani, Penning)

- Active gauges have electronics incorporated in the sensor head
- Used in radiation free or low radiation areas
- Signal conditioning very close to the sensor allows cabling cost reduction

Huba Pressure transmitter 0-1.6 bar
+/-13.5VDC supply
0-10V output
Used in LHC arcs (QRL + MAG)

Pfeiffer PKR251

Penning electronics
Pirani custom electronics
24VDC supply
0-10V output
Used in low radiation areas

Pirani/Penning gauge head
Used in LHC arcs (QRL, MAG, beam)
Hot-cathode ionization gauge (Bayard-Alpert)

- Electrons are emitted by the heated filament and attracted by the grid potential (150V)
- Ionization of gas molecules inside the grid; ions are attracted to the collector
  \[ I^+ = S \cdot le^{-} \cdot p, \quad S \sim 100; \quad \text{current from } 10^{-6} .. 10^{-13} \text{ A} \]
  Pressure measurement from \(10^{-5} .. 10^{-12} \text{ mbar}\); uncertainty \(\sim 10\%\)

- Modular cards for: Electrometer, grid and filament supplies, communication
- Needs calibration; 100fA resolution
- Voltage step-down transformer used for filament heating
- Profibus DP connection; 0-10V output measurement

![Diagram of the ionization gauge with labels: Filament, Grid, Collector, Voltage, Currents](image.png)
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How to measure low current?

Electrometer

\[ V_{OUT} = R_f \cdot I \]

Electrometer, piece wise linear

\[ V_{OUT} = R_k \cdot I \]

- Several decades of current (pressure) to measure
- Relays need to be controlled
- Special relays with low leakage current
- uC needs to know the combination of resistors
- Current measurement from $10^{-4}$ to $10^{-13}$ A
- GΩ resistance for high gain

\[ R_k \] is a combination of \( R_1 \) to \( R_n \)
**How to measure low current?**

Logarithmic electrometer

\[
V_{OUT} = \left(1 + \frac{R_1}{R_{TH}}\right) \frac{kT}{q \cdot \log_{10} e} \cdot \log_{10} \left(\frac{I_{in}}{I_{ref}}\right)
\]

- \(q\): electron charge
- \(K\): Boltzmann constant
- \(T\): absolute temperature

- Log amp compress the dynamic range of signals
- Sensitive to temperature
- Can be slightly compensated
- Current range from \(10^{-4} \) .. \(10^{-13} \) A
Offset and noise current sources

- **Volume resistivity**: leakage of current directly through the material
- **Surface resistivity**: leakage across the surface due to surface contaminants and humidity
- **Water absorption**: leakage dependent on the amount of water that has been absorbed by the insulator
- **Piezoelectric effects**: charges created due to mechanical stress
- **Triboelectric effects**: charges created between a conductor and an insulator due to friction
- **Dielectric absorption**: tendency of an insulator to store/release charge over long periods
- **Temperature**: expansion or contraction of insulators; temperature drift of the electrometer
- **Ionizing radiation**: charges created in the cable, degradation of the insulator
- **Input bias current**: offset current when input of the electrometer left open; compensated by calibration

### Properties of Various Insulating Materials

<table>
<thead>
<tr>
<th>Material</th>
<th>Volume Resistivity (Ohm-cm)</th>
<th>Resistance to Water Absorption</th>
<th>Minimal Piezoelectric Effects</th>
<th>Minimal Triboelectric Effects</th>
<th>Minimal Dielectric Absorption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Teflon® PTFE</td>
<td>$&gt;10^{18}$</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>Sapphire</td>
<td>$&gt;10^{18}$</td>
<td>+</td>
<td>+</td>
<td>0</td>
<td>+</td>
</tr>
<tr>
<td>Polyethylene</td>
<td>$10^{16}$</td>
<td>0</td>
<td>+</td>
<td>0</td>
<td>+</td>
</tr>
<tr>
<td>Polystyrene</td>
<td>$&gt;10^{16}$</td>
<td>0</td>
<td>0</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>Kel-F®</td>
<td>$&gt;10^{18}$</td>
<td>+</td>
<td>0</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td>Ceramic</td>
<td>$10^{14}$–$10^{15}$</td>
<td>-</td>
<td>0</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Nylon</td>
<td>$10^{13}$–$10^{14}$</td>
<td>-</td>
<td>0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Glass Epoxy</td>
<td>$10^{13}$</td>
<td>-</td>
<td>0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>PVC</td>
<td>$5 \times 10^{13}$</td>
<td>+</td>
<td>0</td>
<td>0</td>
<td>-</td>
</tr>
</tbody>
</table>

**KEY:**
- + Material very good in regard to the property.
- 0 Material moderately good in regard to the property.
- - Material weak in regard to the property.

Mostly used at CERN

e.g. FR4 (PCB circuit)!

**Properties of Various Insulating Materials**
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Sputter Ion pumps (SIP)

**Principle**
- Composed of several Penning cells
- \( I^+ = K.p^m, \ m \sim 1; \) current from \( 10^{-2} \ldots 10^{-8} \) A
- Pressure measurement \( 10^{-4} \ldots 10^{-10} \) mbar; uncertainty \( \sim 50\% \)
- Ions bombardment of the Ti cathodes \( \Rightarrow \) Sputtering & deposition of Ti
- Reactive gases pumping effect (stable)

**Controller**
- Provides 0-10V output measurement; protection relays
- Needs to be calibrated
- Controlled through remote I/O station; up-to 40 controllers
- Linear power supply (heavy); HV transformer + voltage multiplier
- Ion pumps are used as interlock source

Installed in ELENA
Under evaluation in other machines
Titanium Sublimation Pumps

Principle
• Titanium filament supplied with high current (~ 40 A)
• Filament is heated until it reaches the sublimation temperature (1300 °C)
• The surrounding chamber walls are coated with thin film of clean titanium
• High pumping speed for getterable gases (CO₂, CO, N₂, H₂O, etc)

Power supply
• Power supply with 230VAC; power modulation using thyristor
• Due to long cable, voltage step-down transformer close to the sublimator
  230V; 1A => 6V; 45A
• Provides current and sublimation measurement

PLC-based
• Up to 8 Power supplies per remote I/O crate
• Can be remotely controlled by PLC (S7-300)
• Sublimation and degassing function, time management
Primary Pump
- Monophase 230VAC or triphase 380VAC induction motor
- Controlled by power relay; protected by thermal relay
- Power provided locally (in the tunnel)
- Pump used: Edwards RV12

Turbo Molecular Pump
- Brushless DC motor, w/ or w/o position sensors (Hall)
- Ceramic ball bearings and permanent magnetic bearings
- Separated controller:
  - RadTol in tunnel, for ARCs;
  - standard in service areas, for LSS)
- 24V, 48V or 72V; I < 10A; Frequency from 0 .. 1000Hz
- Pfeiffer HiPace300 + TCP350 (LSS+DS)
- Alcatel ATH300i + ACT250R (ARCs)

PLC-based
- S7-300 PLC used for the process control
- I/O signals to control the turbo controller + valves
- Connected to the master PLC as a slave PLC
**Simplified VPG Control Process**

1. Turn on Primary Pump (VVP).
2. Once VPP reaches nominal state, open intermediate valve (VVI).
3. Wait a fixed time for VPP to provide the required backing pressure and turn on the Turbo Molecular Pump (VPT).
4. Once VPT reaches nominal speed, enable the manual opening of the gate valves (VVR1 and VVR2).
5. Manually open VVR1 or VVR2 to start pumping the volumes.
6. Leak Detection with a Residual Gas Analyzer may be performed through valve VVD.

**Interlocks and Venting**

1. In case of problems, valves VVR1 and VVR2 are automatically closed and interlocked to avoid accidental venting.
2. Once the valves are closed, VPT and VPP are turned off and venting valves VVP and VVT are temporarily open to vent the pumps.
Temporary pumping is performed by mobile pumping groups

- Mobile & self-contained turbo-molecular pumping groups with all required components
- Connected to the Profibus network in the tunnel
- On-board PLC based control (S7-200, being upgraded to S7-1200)
- Integrated in the Vacuum SCADA using Profibus
- Control and monitoring locally (touch panel) or remotely (SCADA)
Mobile Bake-out Racks

The Bake-out process is managed by mobile Bake-out Racks

- Self-contained, compact and mobile solution
- PLC based (S7-300), fully designed in-house
- 24 controllable bakeout channels
- Type-E thermocouples for temperature measurement
- PID control for the temperature regulation loops
- Actuation of the heating elements using solid state relays
- Integrated in the Vacuum SCADA using Profibus (available in the tunnel)
- Control and monitoring: locally (touch panel) or remotely (SCADA)
Sector Valves

Sector valves controlled by CERN-designed electronics

- Europa crate which can control up to 8 valves
- Up to 4 crates can be chained together to control a maximum of 32 valves
- Each valve is controlled by an individual CPLD-based card, providing basic functionality
- The crate communicates with the PLC through a parallel data bus, using a custom protocol
- All interlocks are implemented within the crate and cards, and thus independent of the PLC
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Sector valve Interlock chain (LHC)

VVS-1 Ctrl. ➔ VVS Ctrl. ➔ VVS+1 Ctrl.

Interlock from/to VVS-1 ➔ Interlock from/to VVS+1

Upper thresh: 2.10^{-6} mbar
Lower thresh: 1.10^{-6} mbar
Direct beam dump request

- Pressure interlock
- Valve in a not-open position
- Vacuum system protection
- Machine protection
Interface with the other systems

MKI (Injection Kickers)
Beam Vacuum

Analog + Digital signals
Provided by SIP + Penning
Dump the beam, stop the HV

ADT
(Transverse Dampers)
Beam Vacuum

Analog + Digital signals
Provided by Penning
Dump the beam, Stop the HV

MKB (Diluters)
Beam Vacuum

Analog + Digital signals
Provided by SIP and Penning
Dump the beam, Stop the HV

Vacuum system

RF system
Beam + insulation vacuum

Analog + Digital signals
BV: SIP + Penning
IV: Pirani
Dump the beam, stop the RF + HV

DUMP target
Nitrogen pressure

Software link
Provided by Piezo
Dump the beam (SIS)

Cryogenics system
Insulation Vacuum

Digital signals
Provided by Pirani + Piezo
Stop the cryo-compressors
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• Higher beam energy (was 3.5 TeV), now 6.5 TeV per beam, foreseen 7 TeV
• 25 ns operation (was 50 ns), now higher beam gas interactions
• Ion runs have high impact on TID (Total Ionizing Dose)
• **HL-LHC**: integrated luminosity will increase by a factor of 10 (from 300 to 3000 fb⁻¹)
• Increase of luminosity will increase the TID in the LHC

Data from RCWG

Run 1+2+3+HL-LHC 2009-2035
Run 1+2+3 2009-2023
Run 1+2 2009-2018
• Strong radiation-induced effects already at 15 Gy: pressure readout 10x the non-irradiated reference

• At the end of the gauges lifetime under radiation: pressure readout 10 000x the non-irradiated reference

• First gauge stopped working at 22 Gy and none survived more than 60 Gy
After 350 Gy, there is supply voltage drop of 7% / kGy

Vmin to maintain valves open varies between 15-20 volts and depends of several parameters (age of the valve, mechanical stress, compressed air pressure, etc.)

Drop of 20% in 3 years in some critical areas (IT): risk of closing pumping group valves
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Radiation tolerant electronics

Gauges

- Design a new radiation-tolerant conditioning circuits of all 3 gauges (Penning, Pirani, Piezo), able to stand cumulated dose beyond 2035

<table>
<thead>
<tr>
<th>Active gauges</th>
<th>Penning #</th>
<th>Pirani #</th>
<th>Piezo #</th>
</tr>
</thead>
<tbody>
<tr>
<td>DS (LS2)</td>
<td>16</td>
<td>16</td>
<td>48</td>
</tr>
<tr>
<td>ARC (LS3)</td>
<td>324</td>
<td>324</td>
<td>120</td>
</tr>
</tbody>
</table>

- Other issues not related to Radiation:
  - 4-20 mA signal transmission
  - Improved Pirani calibration circuit
  - Flexible design for different type of gauges
  - Modular and accessible to improve intervention time

Fixed pumping groups

- Remove completely electronics from local powering crate in the LSS areas
- Additional electromechanical devices, such as remote control of thermal relay and passive current measurement for the primary pump shall be included in the modified local crate to improve remote intervention
PLC-based Sector valves & Interlocks controls

MASTER PLC (SIMATIC 400/1500)

REMOTE I/O ET200SP +CPU

Previous Interlock

Next Interlock

VACUUM CONTROLLER

TPG 300 CONTROLLER

VPI CONTROLLER

INTERLOCK INTERFACE CRATE

VVGS INTERFACE CRATE

REMOTE I/O ET200SP +CPU

INTERLOCK INTERFACE CRATE

VACUUM CONTROLLER

TPG 300 CONTROLLER

VPI CONTROLLER

Previous Interlock

Next Interlock

BIC

Profinet

Ethernet
Profibus

- A Profibus network is permanently installed in the tunnel for the connexion of mobile devices to the master PLC
- Address conflicts due to large number of devices and limited number of addresses per network
- Wrong connection often bring down the whole network
- Wear and tear of the physical network components (connectors and cables)

Wireless – GPRS/3G/LTE

- A leaky feeder antenna already provides GPRS/3G/LTE connectivity in all the accelerator tunnels
- A wireless communication method for mobile devices is being developed based on this technology
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Vacuum controls architecture

Supervision layer

Control layer

Field layer

Supervision Layer

The Proton Synchroton Control Room – 1974 – Copyright CERN
What is SCADA?

**Supervisory Control And Data Acquisition** – Software that:

- Communicates in real-time with controllers running the vacuum process
- Presents data to operators using a graphical user interface (GUI) in order to:
  - Check the process / react to alarms / interact with devices
- Archives historical data
  - Operators can check what happened in the past

CERN’s vacuum SCADA is based on **WinCC-OA (Open Architecture)** from Siemens (former PVSS from ETM).
Choosing a SCADA system

Many other SCADAs are available. Examples:
EPICS - Experimental Physics and Industrial Control System (www.aps.anl.gov/epics/)
TANGO - (http://www.tango-controls.org/)

What are the factors to take into consideration when choosing a SCADA software?

- **Openness**
  - How easy can custom features be built?

- **Scalability**
  - How many devices can it handle?
  - How many users can it handle?

- **Connectivity**
  - Which drivers does it support?

- **Multiplatform**
  - Suitable for Windows and Linux users?
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WinCC-OA is **modular**: each functionality is handled by a specific unit, called a manager.

The software architecture is built around the **Event Manager**:

- responsible for holding variable data in memory and distributing it to other managers.

User interfaces

Control (CTRL) – Custom scripts (ex: SMS alerts)

Application Programmer Interface (API) – Interfaces with other systems

Process Image and History – provide current and past states of all variables

Driver Managers – handle the communication between the supervisory application and the PLCs
A practical example on data flow: what happens when a Valve changes state?

User Interface

Event Manager

Driver Manager

PLC

Get current valve state

Valve is open

Req. change notification

Value change ?

Value change ?

Value change ?

Valve is open

Valve is closed

Update widget

check field value

check field value

check field value

check field value

Value change ?

Value change ?

Value change ?

Valve is closed
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In theory, it can be done manually:

**SCADA**

- VG1
  - VG1.status
  - VG1.pressure
  - VG1.residualPressure
  - VG1.emissionCurrent
  - VG1.collectorCurrent
  - VG1.modulationFactor
  - VG1.sensitivity
  - VG1.gain
  - VG1.degasTime
  - VG1.gridVoltage
  - VG1.warnings

- VG2
  - VG1.status
  - VG1.pressure

**PLC Memory**

- status
- pressure
- residualPressure
- emissionCurrent
- collectorCurrent
- modulationFactor
- sensitivity
- gain
- degasTime
- gridVoltage
- warnings

**Controller 1**

**Ion Gauge “VG1”**

**Controller (...)**

**Instrument (...)**

...(more details)
Control System Configuration

Other parameters need to be configured for each Datapoint:

- Archiving (short and long term archiving)
- Alarms
- Publishing to other services

Once the datapoints are all declared, panels (UIs) can be developed:
Why configuration cannot be done manually?

On LHC alone there are nearly 92,000 vacuum datapoints and dozens of panels:

Just for the datapoints alone, if you were to configure all that manually

Datapoint 1

92000 datapoints later
The vacuum FrameWork (vacFW):
• Automates configuration and synoptic building
• Provides vacuum functionalities on top of WinCC-OA
1. Users add, modify and remove equipment using the **Vacuum DB Editor**

2. Within the DB Editor, an Export software generates SCADA and PLC configuration files

3. SCADA configuration files are imported into the SCADA

4. PLC software is downloaded to PLCs

5. The PLCs will now communicate with new/modified devices and these will be displayed in the SCADA

**SCADA and PLC memory mapping is done automatically by the DB Editor**
Behind the scenes, the Vacuum DB-Editor interacts with several databases, where the configuration data is stored.

vacDB

- **Master DB**
- **LHC**
- **SPS**
- **CPS**

**Vac DBEditor**

- **Layout DB** (equipment positions & hierarchy)
- **Survey DB** (geographical information)

**SCADA configuration files**

**export**

**PLC Software**
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- **Vacuum Functionalities**
- Applications, servers and networking
- Enterprise Asset Management
Functionalities of a Vacuum SCADA

Automatic Drawing of Accelerator

Automatic Synoptic Drawing

Pressure profiles
Device list

<table>
<thead>
<tr>
<th>Device</th>
<th>Sector</th>
<th>Status</th>
<th>Value</th>
<th>PLC</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>WSA_2010</td>
<td>159</td>
<td>Opened</td>
<td>7.72</td>
<td>M-BA2</td>
<td>Vary small leak (15±5 mbar)</td>
</tr>
<tr>
<td>WSA_1000</td>
<td>175</td>
<td>Closed</td>
<td>7.72</td>
<td>M-BA2</td>
<td></td>
</tr>
<tr>
<td>WSA_2000</td>
<td>170</td>
<td>Closed</td>
<td>7.65</td>
<td>M-BA2</td>
<td></td>
</tr>
<tr>
<td>WSA_1120</td>
<td>170</td>
<td>Closed</td>
<td>7.65</td>
<td>M-BA2</td>
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Global Actions

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<th>Equipment</th>
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<th>Action</th>
<th>Action</th>
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<tr>
<td>PS</td>
<td>VGP_T</td>
<td>Switch on all Penning Gauges</td>
<td>Switch off all Penning Gauges</td>
<td>Switch all Penning Gauges on forced</td>
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<tr>
<td>PSB</td>
<td>VGP_BAD</td>
<td>Set to auto all Penning Gauges</td>
<td>Switch all Penning Gauges on forced</td>
<td></td>
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<tr>
<td>LEIR</td>
<td>VPG_PA</td>
<td></td>
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<tr>
<td>AD</td>
<td>VYR</td>
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<tr>
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<td>YPS</td>
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<tr>
<td>TL_Linacs</td>
<td>YYG_PS</td>
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<tr>
<td>PR0</td>
<td>Ga</td>
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<tr>
<td>PR00</td>
<td>Ga</td>
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</table>

SMS Notifications

- **Device list**
- **Global Actions**
Functionalities of a Vacuum SCADA

Equipment State history

Multi trend panel

Replay
Functionalities of a Vacuum SCADA

Widget help panels
Sharing Vacuum Data

Vacuum pressures upon beam-dump

XPOC

Unlimited Retention Archiving Database

Central Alarm Service

Vacuum SCADA

External SCADAs

Cryogenics

 Beam Instrumentation

Alarms of all accelerator systems:
Vacuum, Cryogenics, Access Control, Magnets

Short Term Archiving Database

Servers and PLC statuses
Used Memory
CPU usage

Infrastructure Monitoring

No archive data is deleted: slow

Data retention period 1 year: fast

No archive data is deleted: slow

Data retention period 1 year: fast

No archive data is deleted: slow

Data retention period 1 year: fast

No archive data is deleted: slow

Data retention period 1 year: fast

No archive data is deleted: slow

Data retention period 1 year: fast

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Data retention period 1 year: fast

No archive data is deleted: slow

Data retention period 1 year: fast
- Introduction & Vacuum Controls architecture
- Vacuum gauges & controllers
- Low current measurement
- Vacuum pumps & controllers
- Vacuum hardware interlocks & alarms
- Example of radiation effects on Vacuum electronics
- Future trends & developments

- SCADA
- WinCC-OA architecture
- Configuration of a large control system
- Vacuum Functionalities
- Applications, servers and networking
- Enterprise Asset Management
Typically, each accelerator has a dedicated SCADA application
• Different accelerators = different schedules = different time windows for interventions/updates

Each application can run on a dedicated server, or share the server with another application.

The distribution of applications between servers depend on the following factors:
• Expected load (number of devices / users)
• Criticality
• Cost

At CERN:

<table>
<thead>
<tr>
<th>servers</th>
<th>LHC</th>
<th>SPS</th>
<th>CPS</th>
<th>ISOLDE</th>
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<td>HIEISL vac</td>
<td>Linac4 vac</td>
<td>NA62 vac</td>
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</tbody>
</table>
vac controls architecture

Supervision layer

Control layer

Field layer

Network Separated from GPN

Why having a control system on a dedicated network is a good idea

Security
The potential damage that an unauthorized user can cause by accessing a vacuum control system is enormous:
- Activate NEG on atmospheric pressure – fire hazard – months of downtime
- Turning off vacuum gauges – causing beam dump
- Forcing ON penning gauges – equipment damage

To minimize the risk, the network should be designed to be directly inaccessible from outside the organization.

Performance
Network bandwidth is not shared with other services

Availability
Redundancy can be added to improve the availability of the network:
- Redundant switches
- Powering critical elements of the network with UPS
- Introduction & Vacuum Controls architecture
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- Vacuum Functionalities
- Applications, servers and networking

- Enterprise Asset Management
Managing the lifecycle of equipment in a large installation is made easier by the usage of an Enterprise Asset Management system (EAM).

- Equipment Management:
  - Equipment tracking: what do we have? where?
  - Relationships between equipment

- Work Management:
  - Work dispatch: creation of WorkOrders
  - Work tracking: who did what? when?

- Stock Management:
  - Materials & Parts accounting: how many? in which shelf?
What does an Enterprise Asset Management system have to do with a control system?
The challenges:

- Equipment that users see on the SCADA might not be available in EAM
- Manual imports of equipment to EAM are time-consuming and error-prone

Ensuring continuous consistency is of critical importance for the quality of data

The solution:

Develop a tool that integrates the vacuum control system with the EAM system
Control System Integration with EAM

Users can generate WorkOrders directly from the SCADA

Other ideas:

• WorkOrders can be automatically created when an alarm becomes active
Users can see equipment relationships on EAM system.

Example of chain of control: gauge -> gauge controller -> PLC -> Dataserver

Equipment affected by intervention in a PLC:
Conclusion

- PLC-based architecture is well suited for vacuum controls
- Quality of connectors, grounding and cables are essential for reliable measurement
- For low current measurement (pA, fA), several external factors can strongly affect the results
- Interlocks and alarms must be reliable and tested extensively to assure the machine protection
- Electronics shall be tested under radiation before to be installed in radiation areas
- Wireless network can be used with mobile equipment to improve time intervention and cost

- Choose your SCADA software carefully
- If your control system is moderately large – automate configuration
- Distribute your applications between servers wisely
- Protect your control system by having your SCADA on a dedicated, secured network
- Enterprise Asset Management Software helps – specially if it is integrated with the control system
Thank you!
References

The Control System of CERN Accelerators Vacuum
P. Gomes et al., ICALEPCS 2011


Analog Signal Processing – Ramon Pallas-Areny, John G. Webster

Handbook of radiation effects - Andrew Holmes-Siedle and Len Adams

Measurements, Alarms and Interlocks in the Vacuum Control System of the LHC
G. Pigny et al., ICALEPS 2015