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TECHNICAL NOTE

Vacuum Control System for the Photon Beamlines

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Preface

The main goal for the vacuum interlock in the beamline transport and optics is to take care of the vacuum in the beamline and to protect the accelerator against air. For this goal, a programmable logic controller (PLC) is responsible for the motion of all valves. The signals from vacuum pumps, gauges, etc. are read out by the PLC. Based on this information, valves can open or close for a section.

1 Communication

Communication in the context of the beam interlock means the information exchange between the PLC, bus coupler, and controller for components, as well as the information that will be shown to the control person.

1.1 PLC hardware

The PLC will be a Beckhoff system with EtherCAT protocol. The system will be built in a ring structure. The PLC is outside the tunnel and connected to a bus coupler inside the tunnel. With a RJ45 cable, the EtherCAT signal is transferred on wire to the first coupler, from the first to the second coupler, to the third, and so on. The last coupler will convert the EtherCAT signal into a light signal and close the ring to the PLC. This light signal is necessary for the long distance between the PLC and the last coupler.

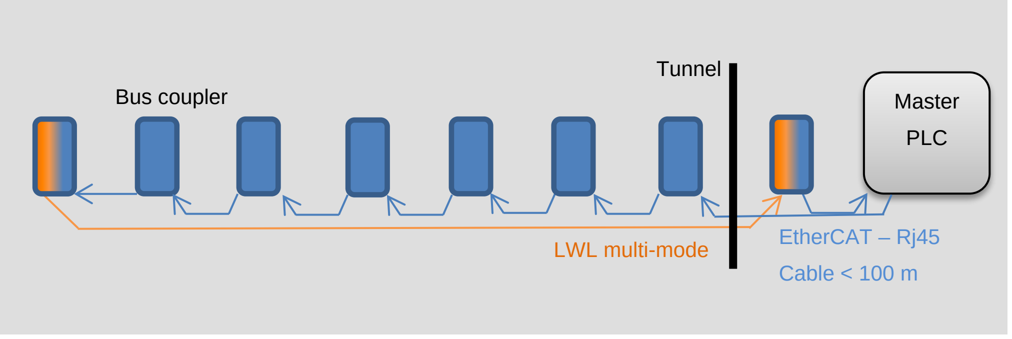

***Figure 1:** EtherCAT Terminals and PLC*

1.1.1 Bus coupler to controller

The bus coupler and additional terminals provide a lot of communication protocols, such as RS232, RS485, and RS422.

For the ion pump controller (Agilent Technologies, Type 4UHV Ion Pump Controller), the RS485 protocol is defined.

For the turbo pump controller (Pfeiffer), the RS485 (EtherCAT) protocol is defined.

1.1.2 Bus terminals

The bus coupler provides an EtherCAT line for different terminals. The terminals read physical signals, switch a voltage, or send and read data protocols.

Table 1: *Function of the terminals*

Function	Type	Low	High	Range	Signal
Digital input	ES1008	0 V	24 V	—	—
Digital output	ES2008	0 V	24 V	—	—
Digital output (fast < 3 ms)	ES2202	0 V	24 V	—	—
Analog input	ES3164	—	—	0–10 V	—
	ES3054	—	—	4–20 mA	—
Communication	EL6002	—	—	—	RS232
	EL6022	—	—	—	RS485
Temperature	ES3314	—	—	—	Type K
	ES3202	—	—	—	PT100
Bus coupler	EK1122	Two-port EtherCAT junction			
	EK1521	One-port EtherCAT fibre optic junction			

1.2 Get information

1.2.1 Vacuum pressure

Ion pumps work with a high voltage of up to 7 kV. The current is in relation to the vacuum pressure, so the information about the vacuum can be read out by the controller for the ion pumps. The controller provides the standard RS 485 protocol and a threshold for an adjustable vacuum pressure. In with a wire connection between the pumpcontroller and the terminals, the PLC can read the vacuum pressure information and alarms. The vacuum pressure is read out via RS485, and alarm signals are read out by the contact threshold in the controller.

If vacuum gauges are installed, they provide a voltage signal of 0–10 V according to the vacuum pressure.

1.2.2 Cooling water flow

With additional boxes, the flow rate can be measured. The box gives a 4 to 20 mA signal according to the flow.

1.2.3 Cooling water conductance

The conductance is measured in the cooling water signal.

1.2.4 Compressed air

The compressed air is measured with a pressure device. The box gives a 4 to 20 mA signal according to the pressure.

1.2.5 Temperatures

For temperatures, a PT 100 (platinum with a resistor of 100 Ω by 0°C) should be used. Only in some special cases is a thermocouple Type K allowed.

1.2.6 Beam shutter

Signal for the open and closed position of the beam shutter must be read out by an end switch with a positive opening operation.

1.2.7 Valve

Position switch for the open and closed position provide the signal for the valve position. The switch closes if the valve is in end position.

1.3 Software

1.3.1 PLC software

The PLC is running with TwinCAT. Logic functions and tasks are programmed here.

1.3.2 GUI software

For the graphical user interface (GUI), a Karabo server is connected to the PLC with TwinCAT. It allows showing all main data. Actions can be done on this level to the PLC, but the logic in the PLC program always has the main responsibility.

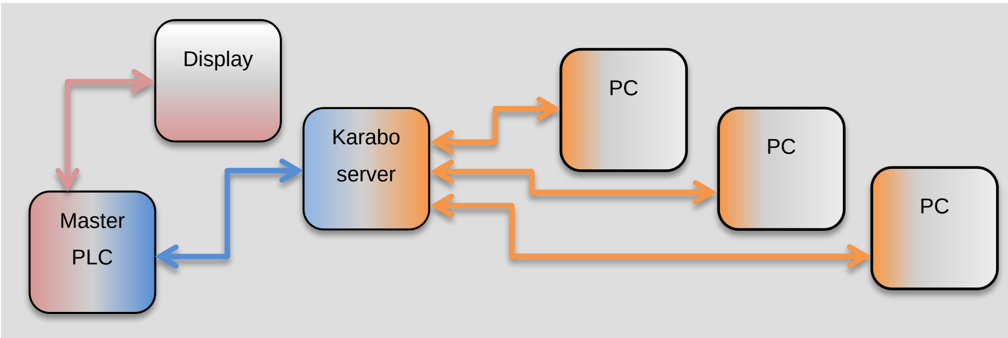

Figure 2: *GUI for the interlock*

The GUI must show all valve status and, if possible, open or close it when clicked. The GUI includes a counter for shutting every valve. The vacuum limit in a line section (between two valves) shows as one piece of information. When clicked, it shows the vacuum pressure for each pump in the line section in numbers (xx 10^{-n} mbar). It includes a “pump power on” counter in hours. For the main information, it shows compressed air in bar, cooling water temperature in °C, cooling water flow in l/h, and failure of one of the two power supplies.

1.3.3 Emergency system

For the main tasks, a display is directly connected to the PLC. It allows a simple diagnostic for the complete system and control components without any network.

1.4 Vacuum interlock MPS

The machine protection system (MPS) is the process used to maintain the safety of the accelerator and to shut down and stop the system, if needed. The shutdown will activate with a change of one bit via the RS 422 protocol.

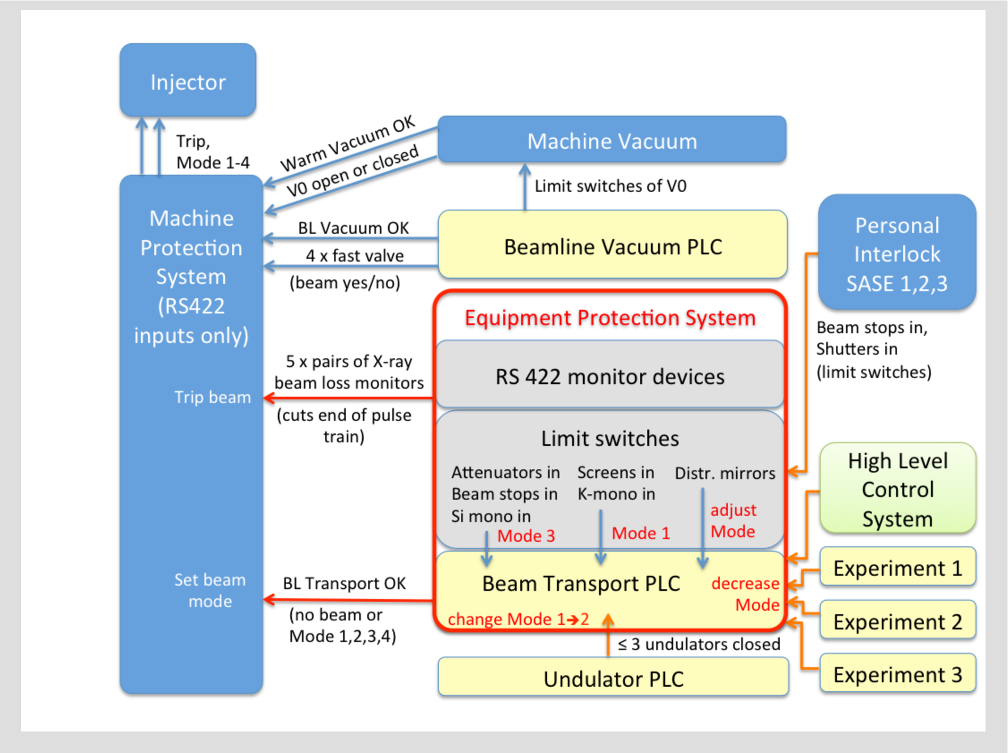

Figure 3: *Communication between vacuum PLC and MPS*

2 Graphical user interface

The main goal of a good GUI is provide an intuitional use and understanding of the system.

2.1 Symbols

Symbols for components are based on the International Electrotechnical Commission's "Graphical Symbols for Use on Equipment" (IEC 60417) and the European Committee for Electrotechnical Standardization's "Safety of Machinery – Electrical Equipment of Machines – Part 1: General Requirements" (EN 60204-1:2006).

In addition, the following symbols are used.

- **Beamline**
  Single solid line in black (Figure 4).
- **Aperture**
  Isosceles triangle with the small side to the experiment side (Figure 8). If there is a temperature alarm, it switches from white to red. The small side is half the length of the side. The inner angle is 70° and 120°.

Figure 4: *Beamline*

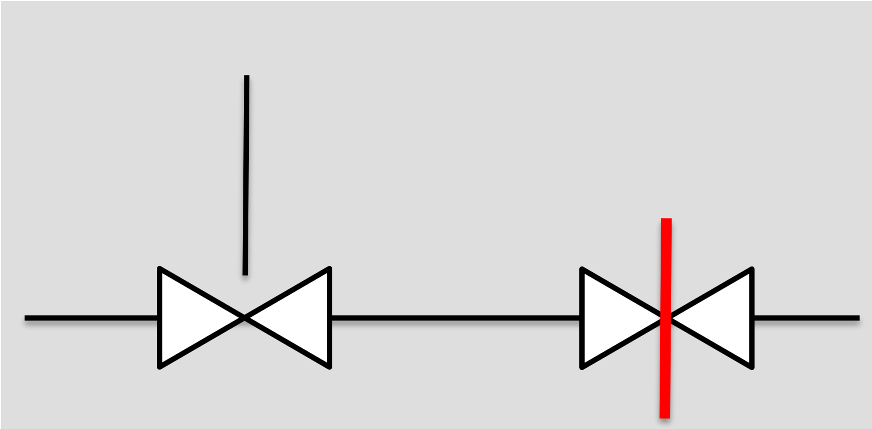

Figure 5: *Open (vertical back line) and closed (vertical red line) valve*

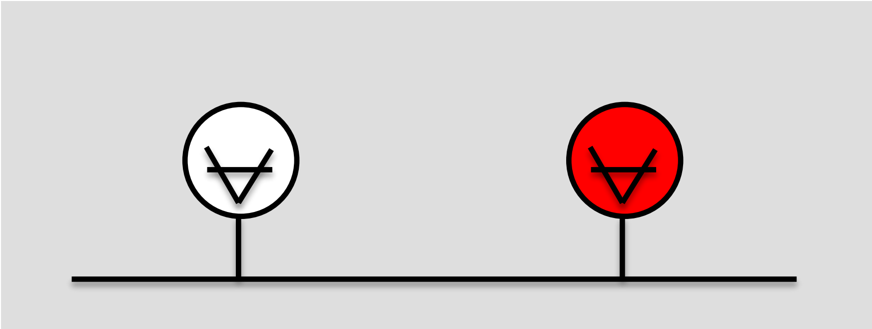

Figure 6: *In-range (white circle) and failed (red circle) vacuum pressure*

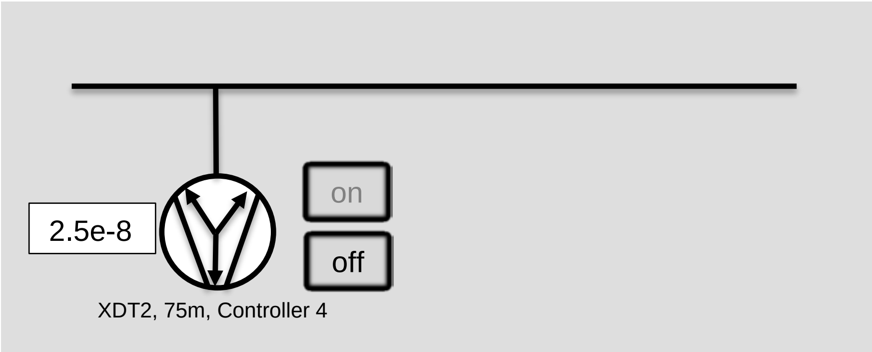

Figure 7: *Ion Getter pump with vacuum pressure and an on/off button*

Figure 8: *Low (white) and high (red) aperture temperature*

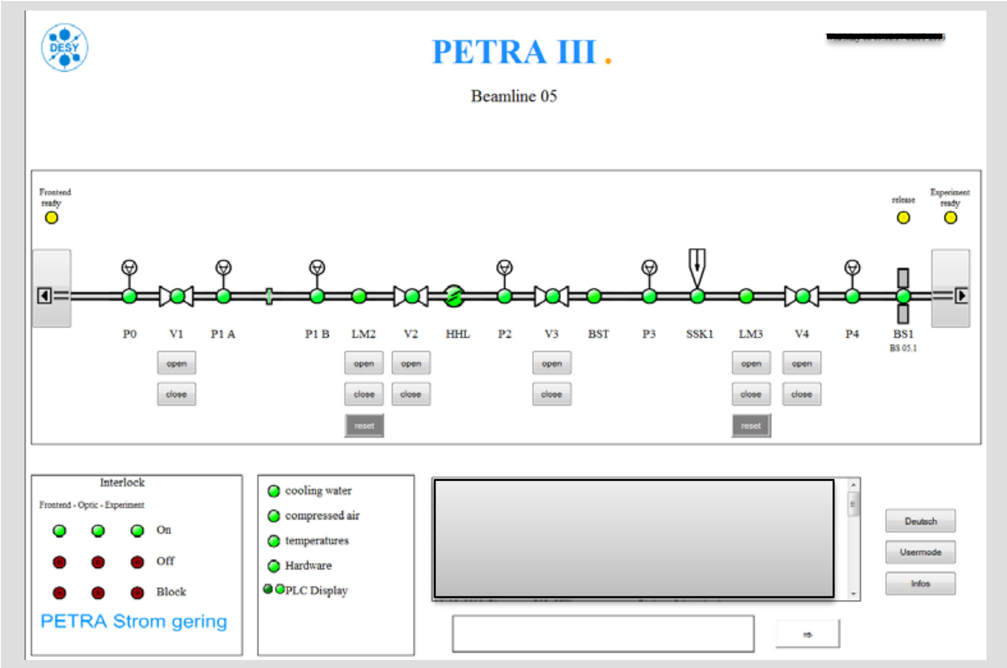

__Figure 9:__ GUI for the vacuum interlock at the PETRA III beamline

2.2 Function

Buttons are visible in different rules to the user. For experts, all buttons are visible. For some users and for guests, no buttons are visible.

2.2.1 Buttons

Buttons are visible only if the user role enables the user to switch them. The caption of a button is black or grey if it cannot be used or is out of order. A single button can have only one function. That is, there are two buttons for any given valve: one for open and one for closed. A single button cannot switch between open and closed.

2.3 Service pages

A service page is useful for a quick and efficient search for problems. This page includes all backup information and hidden properties and a log book.

2.3.1 Service page

The service page shows information such as cooling water, compressed air, hardware status, power supplies status, counter for valves, and so on.

2.3.2 Log book

All activities on the PLC must be logged with a time stamp and shown in a text field. Every action is logged in text format (without any special characters or symbols): “component, action, time”. The component defines kind and place. Action is the change of the component. Time is defined as year, month, day, hour, minute, and second in the format YYYY.MM.DD.hh.mm.ss (e.g. Valve V3102, closed, 2015.03.12.13.43.21).

2.3.3 Archive

Some data will be saved for several years with a low frequency.

The following data must be stored 10 times a minute:

- Vacuum pressure, readout of the controller
- Cooling water temperature
- Compressed air
- Configuration of each Ion pump controller

2.3.4 Automatic email

For some tasks, an automatically generated email will be sent. For minor tasks, an SMS will be sent.

3 Safety

The vacuum interlock system must protect the accelerator vacuum and the vacuum for all beamlines. For this task, there are sensors in the beamline to register a pressure rise and switch fast valves. Ion pumps work indirectly like sensors, and this pressure information is read out. Some failure cases are described in this chapter.

3.1 Power failure

Power failure means a complete disruption of the supply voltage in the whole system, or a failure in one unit without a bridge to the redundancy module. If a power failure occurs, the system must switch into Save status.

In Save status, the following occurs:

- All valves close without power connection.
- Machines dump to protect the valves.

3.2 PLC safety

3.2.1 Beam dump

In some cases, the accelerator must be pumped to protect the beamline and its components.

These cases are:

- Tripping of a fast shutting valve.
- Unexpected not opening of a valve. In this case, the activator is active, and the open end switch is lost.

In each of these cases, an alarm is sent to the user. The alarm indicates which case produced the shutdown.

3.2.1.1 Hardware for beam dump

The machine shutdown is possible on a separate RS422 line. The control unit for a fast shutting valve is directly connected to this line. The PLC shutdown will switch on separate Beckhoff ES2202 terminals with a fast output of < 1 µs.

3.2.2 Machine stop

In some cases, the accelerator must stop to protect the beamline and its components.

These cases are:

- Temperature alarm
- Cooling water flow < n l/h
- Failure of a global variable (see Section 3.1, “Power failure”, on page 14)
- Valve closed by PLC
- Hardware failure
  - — A power supply is not working.
  - — No compressed air.

4 Hardware

The hardware of the PLC, bus coupler, terminals, and power supply is defined in this chapter. The systems with PLC, bus coupler, and bus terminals use a modular technique. In this modular structure, the interpolation of new components can be done quickly and easily.

4.1 PLC topology

For each SASE tunnel, one PLC is responsible for the components. For example, SASE 1 has one PLC, and this PLC controls Experiments 10–12.

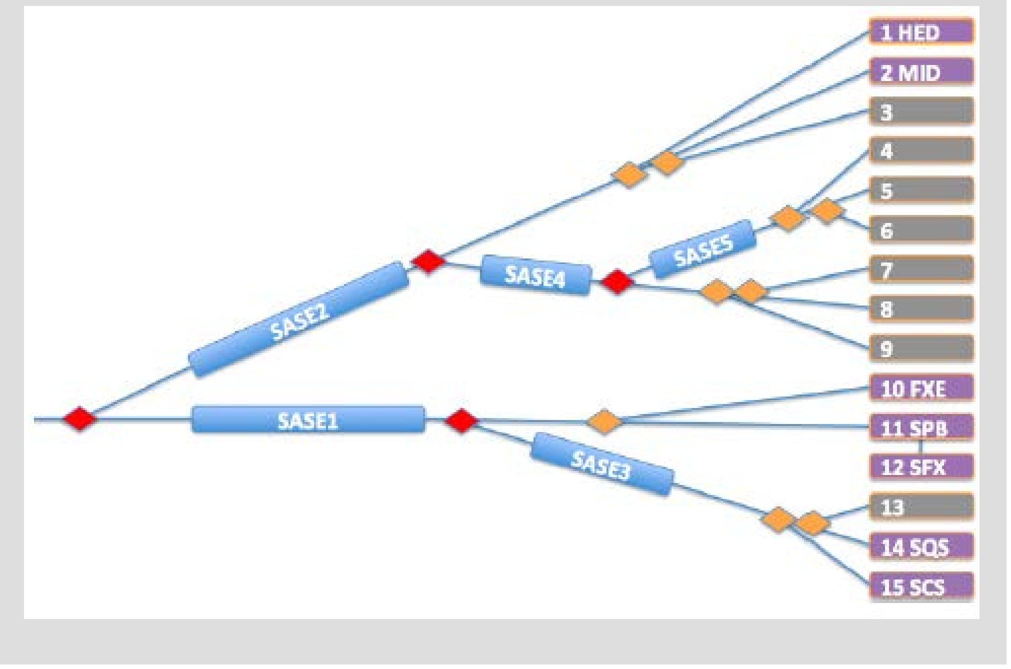

Figure 10: *SASE tunnel definition*

All PLCs work in the same hierarchy without a master PLC. They communicate via EtherCAT with each other and each PLC in the Karabo system.

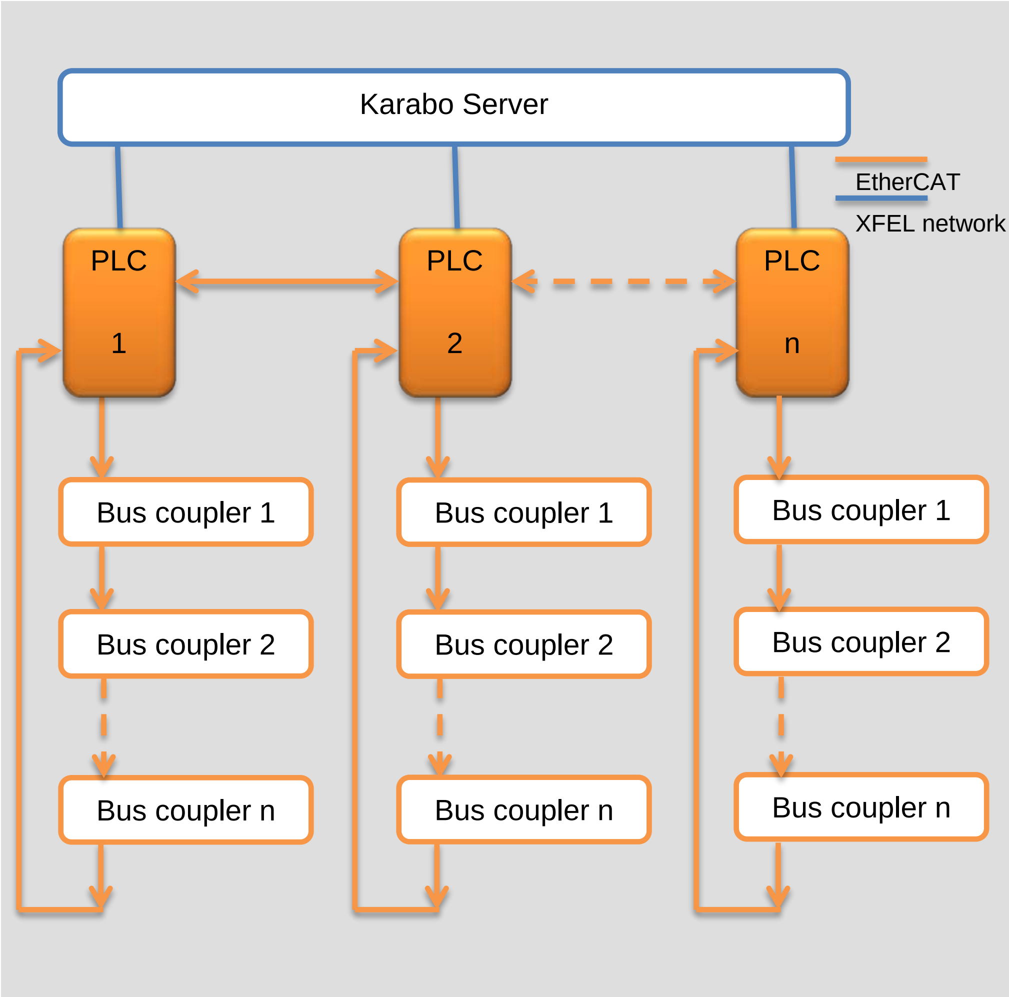

Figure 11: *Topology*

Figure 12: *PLC*

Figure 13: *PLC interaction*

Table 2: *PLC combination*

PLC	SASE	Experiment	
1	1	10	Left
		11	Straight | SPB
		12	Straight-right | SFX
2	2	1	Left | HED
		2	Straight | MID
		3	Right
3	3	13	Left
		14	Straight | SQS
		15	Right | SCS
4	4	7	Left
		8	Straight
		9	Right
5	5	4	Left
		5	Straight
		6	Right

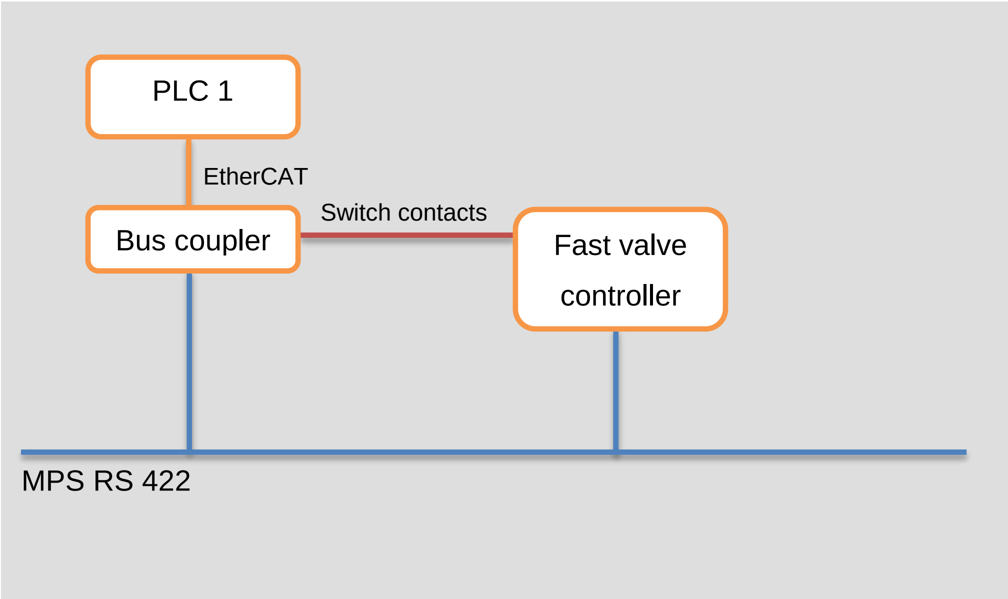

Figure 14: *Signal communication*

4.2 Power supply

The system works with 24 volt DC. Other voltages must be provided with different power supplies and need extra terminals. 24 V are also providing for the components. The 24 V circuit is protected with a glass fuse. The power supply is protected against short circuits and overloads.

4.2.1 Power for PLC

For the PLC, two power supplies with a power balance module provide the 24 V with a USV. The two power supplies are on different phases (L1, L2) and get their own fuse. The power supplies and the balance module have alarm contacts for temperature and overcurrent, which are read out. This voltage is protected with a line filter for each phase.

4.2.2 Power for bus coupler

For each bus coupler in the tunnel, there are two power supplies with a power balance module that provides the 24 V. The two power supplies are on different phases (L1, L2) and get their own fuse. The power supplies and the balance module have alarm contacts for temperature and overcurrent, which are read out.

4.2.3 Power for components

The components for the vacuum interlock, like actuators for valves, end switches, gauges, and so on are served by the power supply of the bus coupler.

4.3 Connectors

The list of connectors are currently being developed by the DAQ and Control Systems group (WP76).

4.4 Cable

For cable inside the tunnel, the DESY specifications are obligatory.

Name: *"Technische Spezifikation Energieversorgung Nr. 13/2005 über brandschutztechnische Anforderungen an halogenfreie und flammwidrige Kabel und Leitungen in den Anlagen von DESY"*

The respective DIN VDE 0100 references apply.

Connections to cable cores to crimp are always preferred before screwing and before soldering.

4.4.1 Labels for cables

Labels for cables have not been defined until now.

Components get a label with the number of the tunnel and the distance from the beginning of the tunnel. Tunnel number (without XTD) – number – component – meter, e.g. "2-V-301" means "Tunnel XTD 2 – valve – 301 m distance from the start of the tunnel".

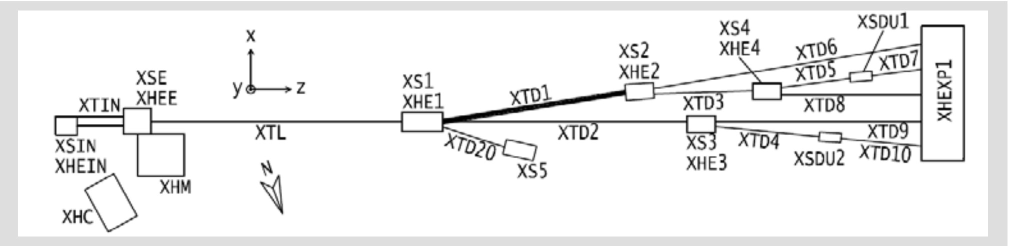

Figure 15: *Name for the tunnel sections and areas*

Table 3: Connectors use for the vacuum interlock

Code	Text in clear	Component	Connection to
V	Valve	Pneumatic valve	Actuator or end switch
P	Pump	Getter pump	HV module
C	Controller	—	—

4.4.2 Cable for valves

For a valve, a cable with 6 cores each 0.5 mm² is available for use. On the PLC side, this cable is directly connected to the terminals. On the other side, it has a connector defined in Table 2 on page 19. Out of this connector, 2 x 2 core cables are connected to the end switches, and a cable with three cores is connected to the activator.

4.4.3 Cable for ion pumps

For the cable from the ion pumps to the high voltage controller, a cable of the following type should be used:

DESY HV-CABLE 0.9/3.2 + 1x0.35mm² - DRAKA – yyyy – ZERO HALOGEN 09 3211173 207171642 nnn m

Wher “yyyy” is the year of manufacturing and “nnn” is the lineal metre.

This cable type includes a core for high voltage that is shielded and a second core for the interlock connection.

4.4.4 Cable for temperature measurement

For a temperature measurement with PT 100, a three-core cable should be used.

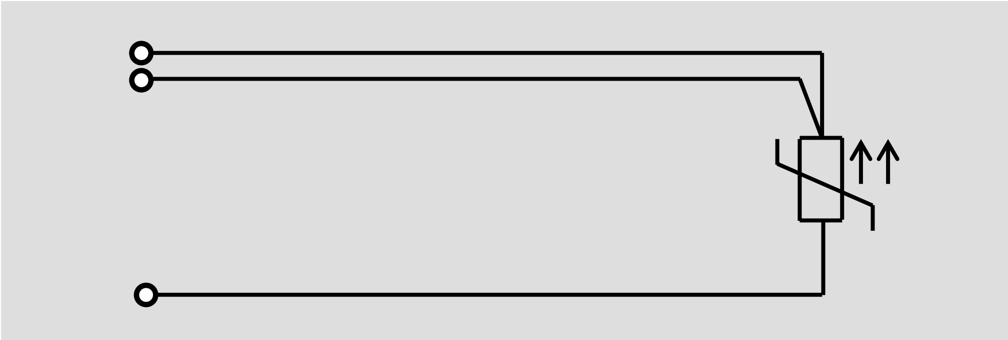

Figure 16: Temperature measurement with PT100 in a three-port cable

For thermocouple Type K, a cable of IEC Standard must be used, with green, red (+), and white (-) isolation.

4.4.5 Cable for creates / bus coupler

The cable colours are currently being developed by the DAQ and Control Systems group (WP76).

5 PLC program logic

The various parts of essential PCL program logic are described in this chapter.

5.1 Global variables

In general, some variables must be provided.

5.1.1 Main global

- Compressed air: *n.n* bar
- Cooling water flow: *nnn* l/h
- Temperatures in range: *nn*°C

5.1.2 Low global

- Power supply for each bus coupler
- Vacuum pressure for each pump: *n.n e–n* mbar

5.2 Main functions

This section describes the main functions.

5.2.1 PLC lock

For work or service at the beamline and against unintentional switching, the PLC can be locked by experts. This lock closes all valves and beam shutters, and prevents them from re-opening—even if someone attempts to switch from the GUI. Locking the PLC is possible only with a physical key at the rack where the PLC is installed.

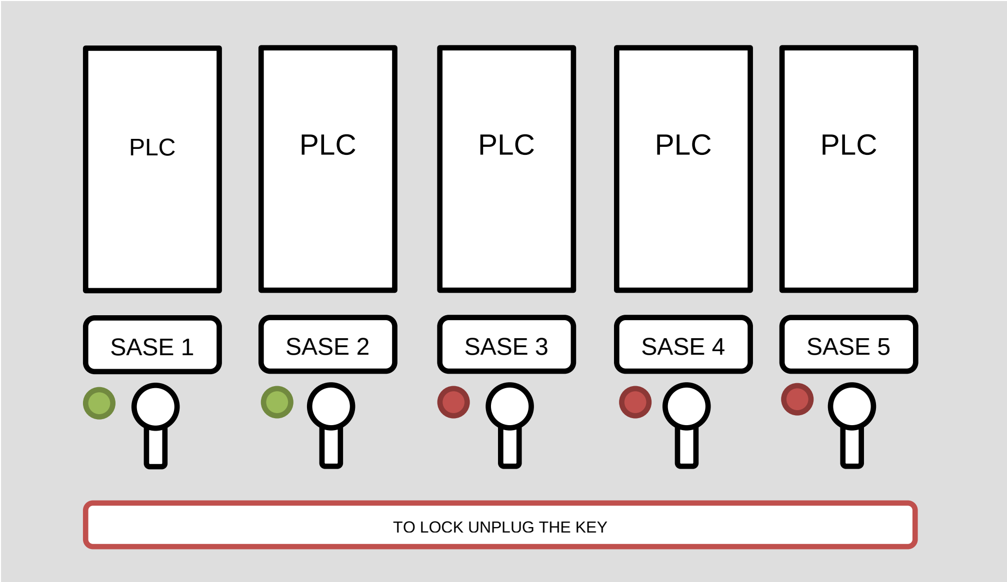

Figure 17: *Key–lock layout for the PLCs*

5.3 Logic functions for components

5.3.1 Logic for valves

Valves are normally open.

They close when one of the following conditions (failures) occurs:

- Vacuum pump fails in a section, and valves close the section
- Global variable fails in the section
- User can close a valve by clicking a button in the GUI
- Activator is active but the open end switch is not active after three seconds

A valve can close only when the beam shutter is closed before the valve. If one pump controller fails for ≤ 3 seconds, the valves does not close the section.

The open and closed cycles are counted for each valve.

Valves can be opened when:

- Beam shutter is closed.
- Beam is running to the next beam shutter or experiment is ready for beam.
- Vacuum pressure on both sides of the valve is ready.

The open and closed positions are registered with end switches. If both end switches are not active for more than three seconds, the PLC must create an alarm.

5.3.2 Ion pump controller

The ion pump controller can be switched on and off by clicking in the GUI. Switching off is possible only when the valve has closed the section. Switching on is possible only when at least one ion pump is running and the section is closed.

The ion pump controller provides the vacuum pressure information of the pump.

The configuration for connected pumps, set points, alarms, and steps of fixed voltage must be adjusted, saved to the archive, loaded to the controller, and backed up to the Karabo server. The information can then be loaded onto new controllers, overriding their standard configurations.

5.3.3 Experiments

For all experiments, an ion pump on the valve side of the experiment is necessary to make sure the vacuum pressure is ready to open a valve.

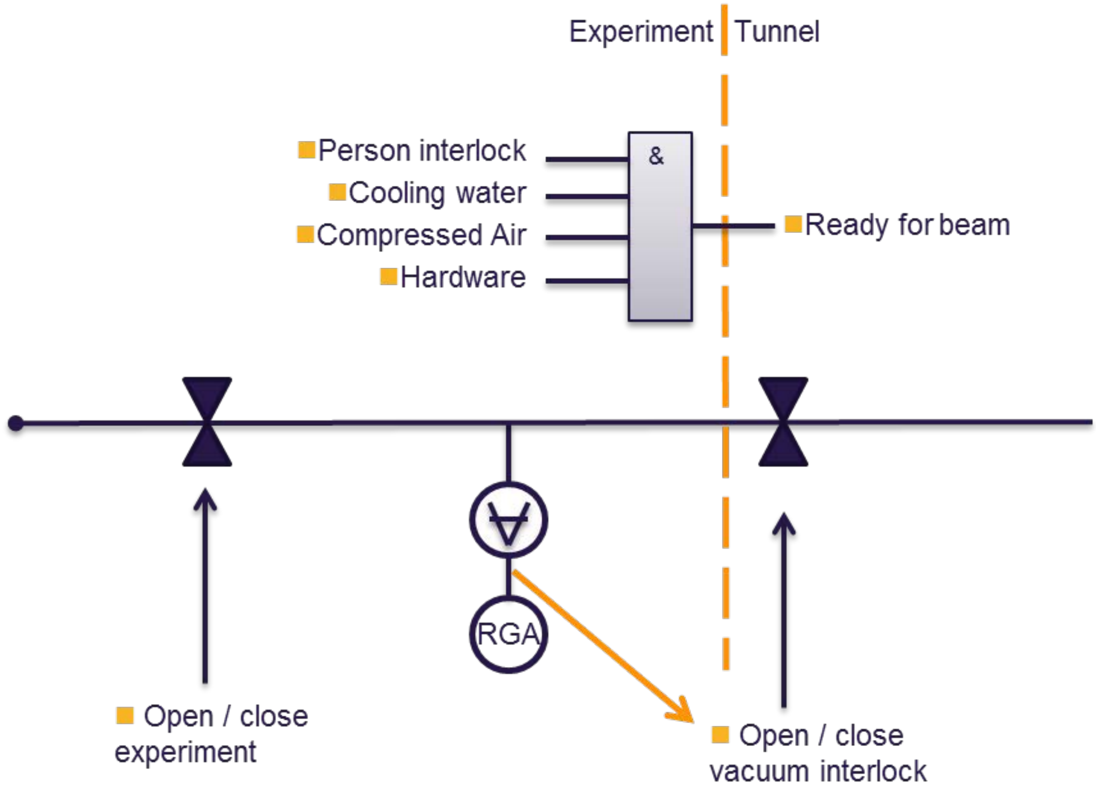

Figure 18: *Signal interchanges for the experiment and vacuum interlock*

5.3.4 RGA on experiment site

For a clean vacuum in the beamline is a residual gas analyser (RGA) between the experiment and the beamline. This RGA is continuous scanning the mass ratio. The definition for a clean vacuum is defined in the "UHV Guidelines for X-Ray Beam Transport Systems" (XFEL.EU TN 2011-001-03). If the mass ratio changes to a bad condition, the beam will switch off and the valve will close.

5.3.5 Fast valve

These valves close directly with their own controller. The PLC gets the status of the valve. The valve can be opened and closed in normal operation through the GUI and can be reset if it closes for a safety reason. Signals of the sensors are read out and shown in the GUI.