VACUUM CONTROL AND OPERATION

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Abstract
The reliability of large vacuum systems is largely dependent on procedures established during installation and, later, on vacuum interventions that concern the exchange of machine parts, leak detection or bakeout. Nonetheless, vacuum equipment and its remote operation play an essential role in maintaining the reliability of the system. Therefore, as early as the design phase, particular attention should be paid to obtaining a precise structure for this system. The vacuum controls should be treated as a sub-set of the overall machine control.

1. VACUUM CONTROL

1.1 Overall layout

The successful operation of large vacuum systems must be based on distributed intelligence; this implies a reliable communication infrastructure between host computers and intelligent vacuum instrumentation.

The vacuum remote control should be designed as an open concept that allows upgrades and modifications of the system. It should be structured so that the user can access and modify different vacuum items on his own and to integrate during commissioning or intervention phases additional control parameters of bakeout or mobile pumping equipment in order to keep track of the performed interventions.

The general control structure should be split into different control levels. The vacuum instrumentation located on the lowest level is connected via dedicated control interfaces to local process computers on an intermediate level. These computers are connected to the server computers via a network, the man-machine interface being the highest level.

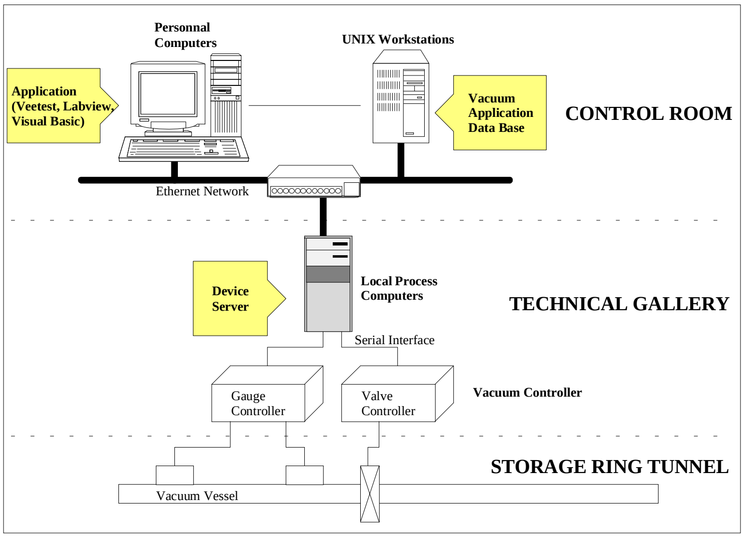

Fig. 1 Control layout

1.2 Vacuum equipment

Depending on the size of the installation and available resources, the vacuum control units to maintain and measure the vacuum system can be either developed in-house or bought as off-the-shelf products. Available control units can be perfectly adapted to the precise needs of the facility, including the hardware distribution, functionality and remote control interfaces. Nonetheless this implies devoting a significant amount of resources and time in order to obtain reliable operation. The more frequent solution is to use off-the-shelf products. In this way benefit from the steady development of the product is gained together with the advantage of a proven technology.

Specifications or selection criteria of vacuum equipment should include built-in microprocessor control; thus a significant amount of the specific operation and error handling is performed by the equipment itself which simplifies the necessary control software.

1.3 Control interface

As most commercial vacuum controllers are equipped with a microprocessor their remote operation is mainly based on a serial interface. Despite some existing electrical specifications, serial lines are not standardised and differences between the different serial interfaces are common. The RS232 transmission protocol is a one-line emission/reception standard which, due to its electrical layout (mass references), is less reliable with regard to communication errors and is limited in transmission distances (20m).

The evolution of differential signals was initiated by the RS422 serial interface. This twisted two-line emission/reception standard improved reliability as polarity changes were used instead of mass references, which may fluctuate between the connected units. The RS485 serial interface is based on the RS422 standard embedded in a multidrop. The use of this interface requires a communication protocol to be able to identify the different users. It has the disadvantage of a multidrop that, in case of a communication problem, renders the whole chain faulty.

The use of a serial interface affords the advantage of allowing a fully remote control of the vacuum equipment. However, software development can be time consuming especially if different hardware platforms are used. Special thought should be given to keeping the interface as simple as possible. The advantage of industrial standard bus systems like CAN, BITnet, G-bus are their reliable communication and a standard bus communication protocol could be used for some parts of equipment, especially for the Programmable Logic Controllers (PLC) or temperature sensors.

1.4 Low-level control

This equipment should be divided into different device groups consisting of pumps, gauges, valves and temperature sensors. In order to maintain identical access to the different device groups an access protocol has to be defined guaranteeing an identical interface for each member of similar device groups, independent of the hardware and the different application programs. This implies the analysis of each vacuum device concerning its functionality, capability and the properties of the different device signals/parameters [1] [2].

The local process computer contains the dedicated software (device server) to completely operate each part of the vacuum equipment. This software handles the routing of requests coming from various applications (e.g. graphical interface, historical archiving). It should be able to monitor the equipment and inform the application in case of incidents.

1.5 High-level control

A common man-machine interface implies that all applications must be able to access the different vacuum devices in an identical way. In order to obtain a simple and reliable control, a client/server architecture should be adopted. The device software on the local process computers are the servers which respond to requests coming from the vacuum applications. Due to the important amount of equipment an event driven data exchange between client/server, rather than polling the server on a periodical time bases, is more efficient.

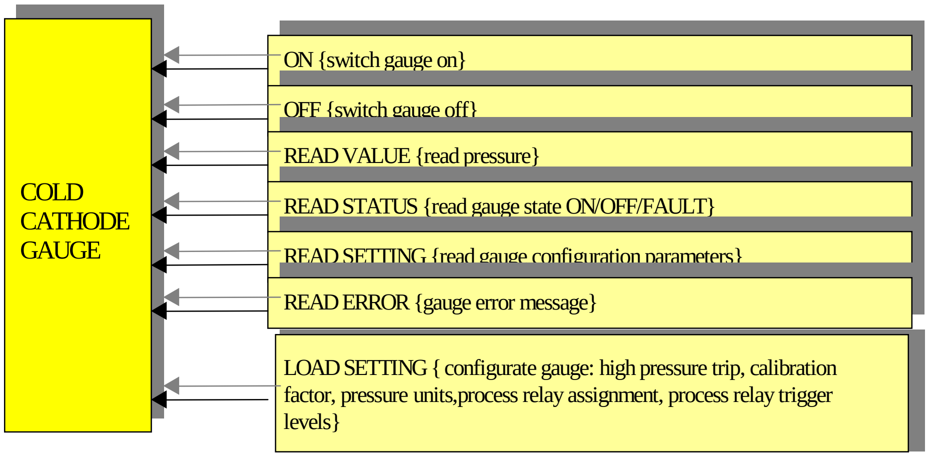

Fig. 2 Device server model

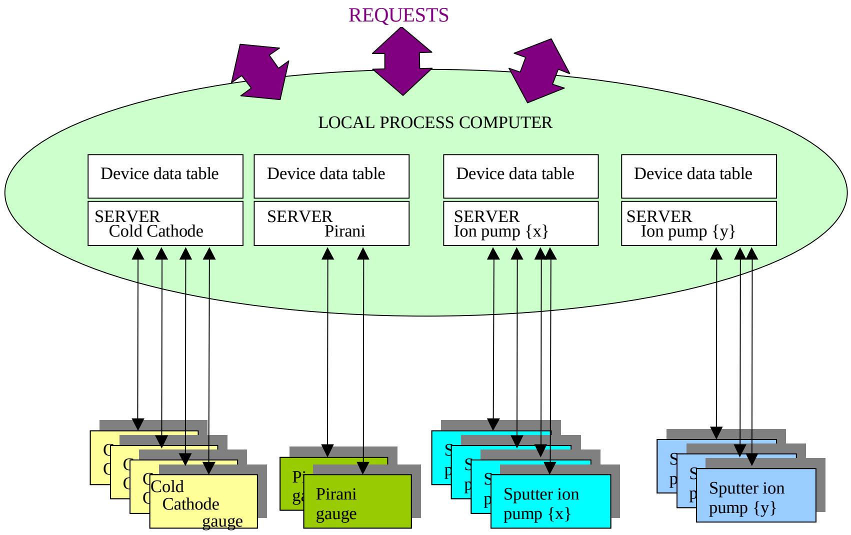

Fig. 3 Lower control level layout

Restarting application programs or dedicated device software should automatically restore the necessary configuration data from a database. This allows a dynamic update of any modification to the vacuum system with the guarantee of having a valid update on all control levels.

The main requirement of a vacuum application program is to visualise the current status of the vacuum equipment, to be able to modify it, to display all relevant physical data and to indicate errors or faulty equipment in an explicit written message. Additional information for the evaluation of the current status of machine parameters (beam current, lifetime) as well as the time stamp must be available.

Apart from the standard vacuum applications, attention should be given to providing simple development tools to create small control and analysis programs and to be able to better specify later application programs or to solve temporary problems.

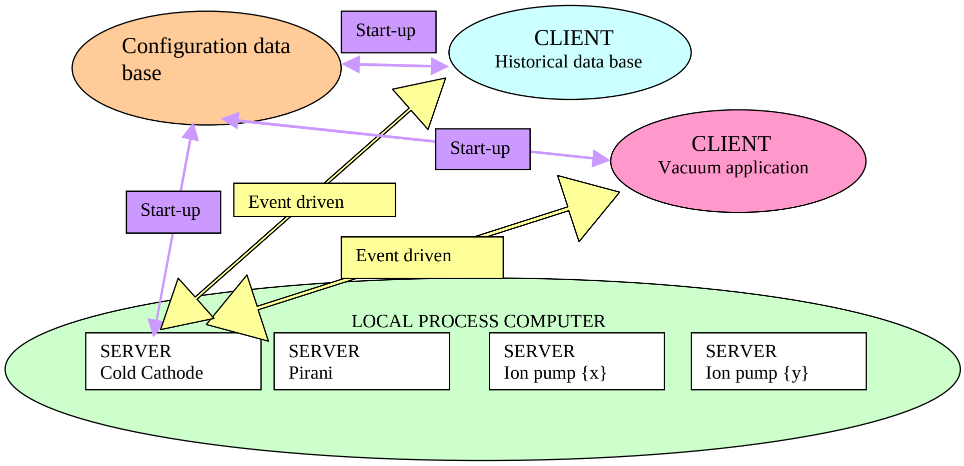

Fig. 4 Higher control level layout

1.6 Database

The size and complexity of control system data implies the use of databases. These reduce the difficulties of maintenance and improve understanding of the behaviour of the system. Commercial database management systems allow access from within the control application via high level languages as well as the possibility of interfacing with commercial packages such as data analyser tools or other data bases [3].

Information concerning the system configuration or measurements, data logging, cables, alarms, equipment maintenance, and failures can be integrated into a common database. This should contain all the necessary information for application programs and device server software [4]:

- ◊ The description of the vacuum system, which includes its physical layout, equipment names, and their position.
- ◊ Communication path definition between the equipment interface and the network address including the necessary communication parameters.
- ◊ Physical characteristics describing each part of the equipment (calibration, process relay assignments, set points).

The archiving and retrieval of historical data becomes an important item as time passes. It enables the identification of leaks, qualifies vacuum conditionings after interventions and enables comparison between different Insertion Device chambers. In the case of the ESRF data is processed in a common database for the machine and beamlines. Up to 3 Gbytes of vacuum data are stored over a year. Initially a commercial database was not available and the storage ring vacuum data was stored in dedicated files with the attendant difficulties of correlating vacuum data with other machine data, and the increasing complexity to extract important amounts of data.

The system should be flexible and easy to use which implies access tools to include new signals or modify the collection processes in a synchronous or asynchronous way with a maximal updating rate of the order of 1 second triggered by changes. Convenient and powerful graphic programs to display and browse the historical data must be available [5]. In addition it should be compatible for use by common spreadsheets or other specialised data analysis programs. A different feature – as important as the data logging of measurements and alarms – is the systematic recording of faulty equipment or material failures such as leaks repaired with varnish, radiation damaged cables, leakage currents on connectors, gauges, feedthroughs, etc. At the ESRF we have started an e-log, based on a database, which allows everybody to access via the Intranet from the various platforms. This enables problems to be identified, gives improved reliability and eases the maintenance burden.

2. INTERLOCKS

2.1 General concept

The choice of industrial Programmable Logic Controllers (PLCs) provides expansion capability and therefore the possibility of an easy upgrade to include changing requirements of storage ring and beamline operation during the installation and operation phases. PLCs are used extensively in industry to control sequential and/or continuous processes. These systems are designed to reliably sustain the harsh industrial environment. Compared to the classic hard-wired systems they provide more functionality but also communication mechanisms, supervision tools or archiving schemes.

At the ESRF the PLCs are connected via a proprietary RS485 interface to the local process computers. The process control part is completely covered by the industrial PLC, whereas the communication mechanisms of monitoring and control have been adopted by the standard control system. This resulted in a partial loss of important off-the-shelf features such as reliable intra-PLC communication or alarm handling. A non-negligible effort was put into the re-design and integration into the accelerator control system.

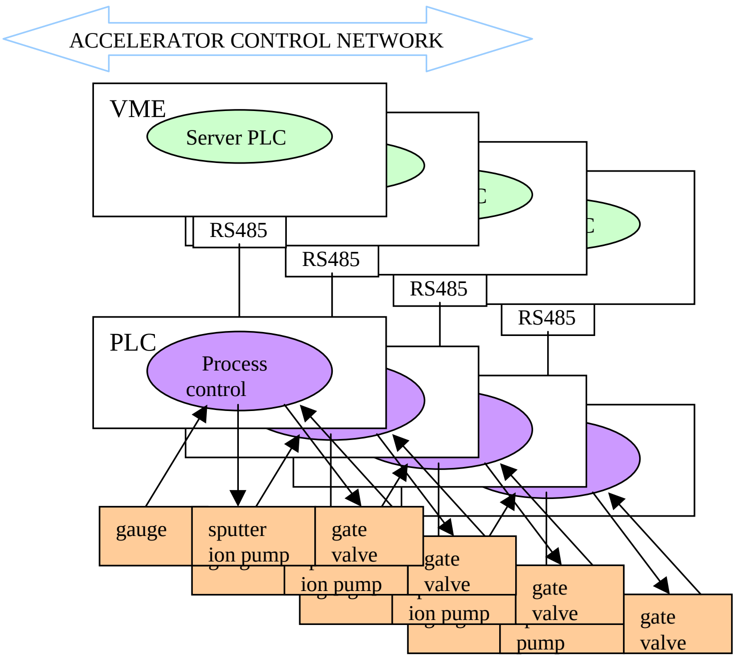

Fig. 5 ESRF layout

Possible evolution could be to use a cluster of PLCs linked together with an industrial field bus and connected to an upper control platform which acts as a supervisor. The different clients access the supervisor instead of each PLC [6]. Based on a modular system with in situ programming or via EEPROM, the PLC provides flexibility. This enables user-friendly upgrades or modifications to interlocks based on software changes, maintaining the principle of dedicated PLC programs using standard software and hardware interfaces.

2.2 Possible design solution

At the ESRF the same interlock strategy has been applied for the accelerators, Storage Ring (SR), Front Ends (FE) and beamlines. Depending on the size and complexity of the system several PLCs can build up the interlock system for SR or beamlines. The vacuum interlock system should be based on modules, which consist of all vacuum equipment inbetween two gate valves or windows. A module should consist at least of a Pirani gauge, Cold Cathode or Hot Cathode gauge, pump and pre-pumping valve.

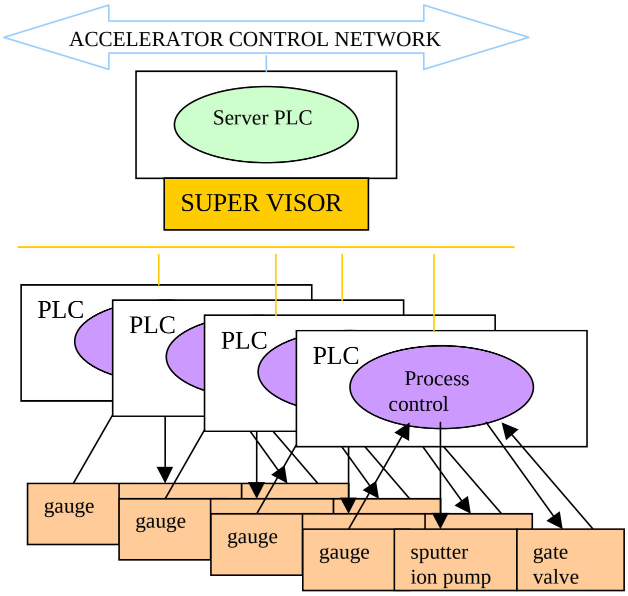

Fig. 6 PLC cluster layout

Apart from the continuous survey and processing of all connected trigger signals, which afford protection for gauges, residual-gas analysers and pumps, each PLC assures sequential processes. This concerns the operation of gate valves, shutters and absorbers related to other safety systems such as the Personnel Safety System, FE or experimental interlock signals. The remote operation via the control system allows a safe access to control vacuum items and allows quick and easy diagnostics in the case of interlocks. For the more complex use on beamlines a master/slave structure has been developed for different PLCs dedicated to cooling, safety shutter operation and beamline vacuum; and for the FE PLCs which operate the different vacuum and shutter elements of the FE.

3. VACUUM OPERATION

3.1 Total pressure measurements

3.1.1 Pirani gauges

These are chiefly used as cheap and simple high pressure gauges, necessary during interventions and for the completion of the total pressure measurements for the interlock system. The stability of these gauges is satisfactory. The use of long cables does not appear problematical with careful earth and mass connection of the gauges and controllers. These gauges remain switched on all the time. At the ESRF the Pirani gauge measurements are used for the interlock system to protect cold cathode gauges, sputter ion pumps and residual-gas analysers operated at high pressure and also during the NEG activation.

3.1.2 Cold-cathode gauges

The pressure monitoring system and interlock system at the ESRF is based on cold cathode gauges. It provides a reliable and stable operation in the dynamic pressure range of the machine (10^{-8} -10^{-10} mbar). The gauges are easy to handle. They are mounted using CF38 elbows or cross tubes without additional photoelectron shielding. Electrical connection is by triaxial cabling because of the long cable length. Special attention is given to the electrical connection since, apart from the HV supply of the gauge, the measured currents are in the 10^{-9} A range, which implies careful earth/mass connections for all gauges and controllers. Occasional electrical leakage currents occur on the electrical connection due to humidity or radiation damage, or on the gauge which can be solved by high voltage conditioning. The gauges are mainly started at about 10^{-9} mbar, which does not present any problems during operation.

3.1.3 Hot-cathode gauges

At the ESRF these gauges are only used in a few places as a reference under static vacuum conditions. Compared to the cold-cathode gauges, the use of these gauges is far more complex. In order to achieve reliable and stable measurements, several parameters need to be considered such as degassing during bakeout and regulation of emission currents. At the ESRF some problems were observed: unstable operation due to frequent filament trips; mounting on a CF63 flange with additional photoelectron shielding; a fair amount of gauge failures (short circuits, broken filaments) and sensitivity to the radiation background which required additional lead shielding.

3.1.4 Sputter ion pumps

Recent ion pump power supplies provide the possibility of obtaining reliable measurements of the ion pump current in the low 10^{-6}A range. Depending on the pump size used, the limit pressure measured should be in the low 10^{-9} to 10^{-10} mbar range. This may give interesting information about the pressure distribution inbetween the gauges during operation. It will make it easier to identify local pressure bumps induced by leaks or malfunctioning of the pumps.

3.2 Partial pressure measurements

Residual-gas analysers (RGA) are included in the standard vacuum monitoring and data logging system to continuously follow a defined number of partial pressure measurements in order to confirm correct vacuum conditions on critical machine parts. They are also used in situ via PCs and the software to confirm correct bakeout, leak detection and RGA maintenance work. In order to achieve reliable measurements a considerable amount of work on system maintenance is necessary. Procedures have to be established to outgas filaments and to calibrate multipliers. The analysers have to be shielded against photoelectrons as well as radiation background.

3.3 Additional diagnostics

At the ESRF thermocouples were installed initially to control and monitor bakeout but have since been included in the standard vacuum monitoring and data logging system, as they have proved to be an interesting diagnostic tool in exotic machine operation modes to trace heating problems. Thermocouples are used since they are simple to handle and inexpensive. Special care has to be taken during their installation to assure a reliable attachment and cabling. It appears that apart from standard location on critical spots (crotch, absorber, bellows, and ceramic chamber) the system should be flexible regarding hardware and software to allow relocation/installation of thermocouples in situ and on the remote control.

3.4 Safety elements

3.4.1 Gate valves

The vacuum systems have to be divided into a sufficient number of sections limited by gate valves in order to isolate sections likely to undergo more frequent changes from sections that should remain stable. These gate valves should be equipped with an electro pneumatic control in order to close vacuum sections in case of pressure increases. This also implies the layout of the FE section and beam lines.

Several failures at the ESRF have proved that the existing interlock system can face accidental venting due to material failures (cavity window) or human errors during interventions. In all cases the incident could be limited to the zone between two pneumatic gate valves.

3.4.2 Fast shutters, acoustic delay lines

The UHV system of the SR has to be protected from vacuum failures in the downstream beamlines. Some of these beamlines are directly connected to the SR vacuum without any physical limitation of a window. At the ESRF each FE has been equipped with fast shutter and acoustic delay line in order to isolate the SR vacuum system in case of an important vacuum failure. Commercial fast shutter systems are available and those installed are working well.

The propagation time of the pressure wave has to be increased by means of additional volumes or acoustic delay lines that consist of a series of baffles [7 – 9]. Tests have shown that the time taken for a wave to travel through a vacuum chamber varies according to the entry pressure, but also depends on the type of failures that vary from accidental manipulation of a valve to a window breakage. Experience gained at the ESRF shows that many vacuum accidents are not dramatic failures requiring the operation of active safety elements. Only in two cases was the fast shutter triggered and prevented the venting of SR vacuum sections. In both cases the failure happened on the first vacuum section on the beamline which is not isolated by a gate valve. In all other cases the beamline vacuum interlock system triggered the closure of the gate valves on the beamline and FE and prevented venting of the FE. Apart from the active safety elements such as fast shutters and acoustic delay lines, special attention has been given to include passive safety elements in the design of critical beamlines by using the sometimes important volumes of optical components (mirror, monochromator) linked with rather small conductance and differential pumping together with a sufficient number of gate valves to prevent the propagation up to the FE.

3.4.3 Comments concerning windowless beamlines

Special beamline layouts, interlock features and procedures have been developed to protect the SR vacuum against accidental venting and contamination from beam lines which do not have a physical barrier between both vacuum systems. In order to protect the SR vacuum the interlock systems of beamline, FE and SR have to be directly linked together.

◊ Accidental venting due to material failure

The mentioned FE acoustic delay line and fast shutter are the standard items. In addition a pressure gauge located on the first beam line module triggers the closure of the gate valves on the beamline and FE. An additional fast acting shutter only on beamlines protects the SR vacuum if an experimental part is placed outside a protection hutch or the experimental set-up is particularly risky (ultra-thin window).

◊ Accidental venting due to human error

The installation of a pneumatic gate valve as one of the first elements in each hutch allows systematic closure of the dedicated gate valve if personal access to the hutch is enabled.

◊ Leaks and contamination

The vacuum pressure of the beamline close to the FE has to be compatible with the SR vacuum. As mentioned earlier the FE gate valves are triggered not only by the FE gauges but also from a gauge located on the first beamline module with a large hysteresis on the trigger level.

If there is an abnormal pressure increase in the beamline the limiting gate valves are closed and cause the closure of the FE absorber. The pressure has to recover by a factor of two from the set point value in order to reopen these gate valves. In the case of an important leak which causes the pressure to rise in the first module the limiting beamline gate valves and FE gate valves will be closed. The FE gate valve will be inhibited until the pressure in the first beam line module has recovered by a factor of 100 from the set-point value.

Additional procedures have been established at the ESRF to protect the SR vacuum against contamination and for example, a partial pressure alarm system has been developed. Residual-gas analysers are installed between the FE and the limiting gate valve to the beamlines. In order to continuously protect the SR vacuum it is necessary to contain the partial pressure measurement in an alarm system connected to the standard beamline interlock system to close shutters and gate valves to isolate the vacuum sections.

◊ Differential pumping

Most beamlines use differential pumping systems to separate UHV from HV vacuum sections. In this cases the ion pump power supplies are also interlocked with the limiting gate valves.

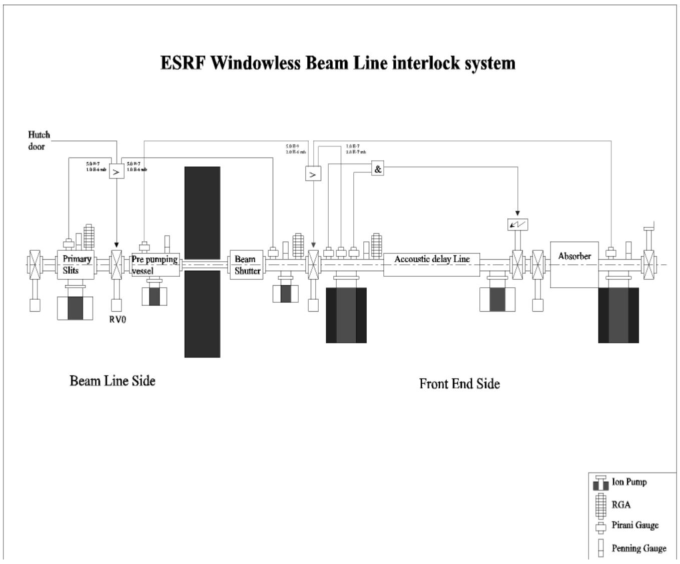

Fig.7 Interlock logic of windowless beamline

4. ACKNOWLEDGEMENTS

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