Beamline Front-End
Control and Instrumentation Manual

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REVISION HISTORY

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1.0 INTRODUCTION

The current revision of this document focuses on Machine Protection for Front Ends.

1.1 DEFINITIONS AND ACRONYMS

Protected State	Devices are in a 'protected state' when not subjected to a level of Synchrotron Radiation which exceeds the device's design.
ACIS	Access Control and Interlock System
BPM	Beam Position Monitor
CCG	Cold Cathode Gauge
E-Beam	Electron Beam stored in the Storage Ring
FE	Front-End
ID	Insertion Device
IOP	Ion Pump
MPS	Machine Protection System
PSH	Photon Shutter
RGA	Residual Gas Analyzer
SR1	Storage Ring 1
SSH	Safety Shutter(s)
TCG	Thermo Capacitance Gauge
VVF	Vacuum Valve Fast
VVR	Vacuum Valve Remote
pOE	Primary optical Enclosure

2.0 FUNCTIONAL DESCRIPTION

The Machine Protection System is designed to protect the machine and components from damage from synchrotron radiation, miss steering of the beam, loss of cooling, and loss of vacuum. The Machine Protection System will ensure the components are in a 'Protected' state. This is accomplished by forcing components into a protected state, by preventing components from being put into an unprotected state, or by removing the source of radiation or heat which would cause damage to the component.

There are three types of Front-Ends (FE) on the CLS Storage Ring. They are the Bending Magnet FE, the Single Insertion Device FE, and the Dual Insertion Device FE.

2.0.1 Bending Magnet Front End

The bending magnet front end is subjected to the photon beam produced by bending magnets. This front end has two redundant photon shutters capable of withstanding the photon beam.

2.0.2 Single ID Front End

The Insertion device front end is subjected to the photon beam produced by a single insertion device. The photon beam produced by an Insertion device can be much more intense than that produced by a bending magnet. The single ID front end is a standard front end which has two redundant photon shutters, each capable of withstanding the photon beam produced by the insertion device.

2.0.3 Dual ID Front End

The dual ID front end has limited space compared to the single ID and BM front ends. The photon shutters on the dual ID front end are not fully redundant. The first or upstream photon shutter (secondary photon shutter) is only capable of withstanding the photon beam produced by bending magnets. The second or downstream photon shutter (primary photon shutter) is capable of withstanding the photon beam produced by insertion devices.

2.1 MAJOR COMPONENTS

With the exception of the Safety Shutters, the following components are controlled and monitored by the Machine Protection System. Major FE components associated with the control system are listed, in the order of the photon beam travel:

1. Secondary Photon Shutter (PSH1) – protects the first Vacuum Valve Remote (VVR1) and Fast Vacuum Valve (VVF).
2. 1st Vacuum Valve Remote (VVR1) – vacuum-tight valve between the SR and Front-End.
3. Fast Vacuum Valve (VVF) – non vacuum-tight valve, protects the SR from a shock wave originating downstream of the Front-End. The fast valve is part of the fast valve system which also consists of a controller and high voltage Cold Cathode sensor (CCG). The HV sensor is located near and measures the vacuum level at the beamline end of the front end.
4. Primary Photon Shutter (PSH2) – protects the Safety Shutter, downstream Vacuum Valves, and optical components.
5. Safety Shutters (SSH) – protects beamline personnel from primary bremsstrahlung radiation directed towards the beamline.
6. 2nd Vacuum Valve Remote (VVR2) – vacuum-tight valve. In some cases the last vacuum valve in the Front-End.
7. 3rd Vacuum Valve Remote (VVR3) – vacuum-tight valve, the last valve between the Front-End and the Beamline.
8. Other vacuum components include: Ion Pumps (IOP), Cold Cathode Gauges (CCG), Residual Gas Analyzer (RGA), Thermal Capacitance Gauge (TCG) and Titanium Sublimation Pumps (TSP).
9. Other mechanical components include: Temperature Monitors (TM), Pressure Transducers (PT), Flow Switches (SWF), Flow Transducers (FLT).

2.1.1 Safety Shutters (SSH)

The two redundant safety shutters are components of the Access Control and Interlock System (ACIS)[1]. When inserted, the SSHs must be protected from the photon beam by the primary Photon Shutter (PSH2). The ACIS will provide a 'PSH Close Request' to the Machine Protection

System (MPS), to close the PSH before closing the SSHs. The ACIS will not close the SSH until the MPS indicates that a PSH is closed. The ACIS will provide the MPS with the position (Fully Open/Fully Closed) of the SSH. The MPS will inhibit the opening of the protecting PSH when the SSH is closed.

The ACIS will allow the SSH to open only after all the appropriate criteria have been met.

2.2 FE LOCK-OUT / OUT-OF-SERVICE

In order to prevent an isolated problem with a FE from halting SR operations for a long period, it may be necessary to take a FE out-of-service. In this case, the FE will be physically locked-out with a key-lock switch located in the FE control racks. The lock-out switch will assert interlocks to prevent shutters and valves from opening, and IDs from being engaged.

A second key-lock switch is available to override FE vacuum interlocks. This key-lock will disable FE vacuum interlocks to the SR VVRs. The vacuum override key-lock will only be effective when the FE is locked-out.

2.3 EQUIPMENT PROTECTION

This section defines the requirements for the protection of the major front end components and the Front End as a whole. Front End components may be damaged when subjected to the photon beam generated by insertion devices and bending magnets when there is current in the SR1 (injection, or stored e-beam).

Protection of certain components requires the insertion of Photon Shutters, Trip of SR RF, disengagement of IDs, or a combination, depending on the situation.

2.3.1 SR RF Trip

Certain conditions will require the Machine Protection system to cause the e-beam in the SR to be dumped. This is to protect FE components which may not be in a protected state due to a FE vacuum trip, or an operational failure of other components.

The dump of SR is implemented by an interlock from the Machine Protection system to the RF system. The RF system implements this RF trip as a ‘soft’ trip which will cause the e-beam to dump within 2ms.

2.3.2 Insertion Devices

Insertion devices produce an intense photon beam when engaged with the e-beam. Many front end components cannot withstand the intense photon beam produced by IDs. Therefore, insertion devices will be interlocked by the front end machine protection system to prevent the IDs from being engaged when FE components are in an unprotected position.

2.3.3 Vacuum Protection

The Front End machine protection system provides vacuum protection by interlocking vacuum-tight valves with the standard MKS CCGs, IOPs, RGAs and TCGs.

The CLS vacuum protection system is design to isolate ‘bad’ vacuum sections. This system is implemented by either ‘Priority 1 Vacuum Protection.’ or ‘Priority 2 Vacuum protection’ strategies.

The Front End will protect the storage ring from contamination from the beamlines. A Residual Gas Analyzer (RGA) will be used to monitor specific molecular species which are likely to indicate a vacuum problem in the beamline.

2.3.3.1 Priority 1 Vacuum Protection

The vacuum protection consists of two redundant systems, a hardware or relay based system and software PLC based system. Each system monitors an independent relay contact provided by the vacuum monitoring components (IOPs, CCGs, etc.). The relay contacts are controlled by set-points configured on each of the vacuum components.

The vacuum protection system monitors the state of vacuum in a given section, between a set of vacuum tight valves. If the vacuum level rises above a predefined set-point (typically $1x10^{-7}$Torr), the valves isolating the vacuum section are closed, as well as the valves isolating any adjacent and attached sections. In a simple straight line section, this results in the closure of two valves on either side of the vacuum chamber where the vacuum fault was detected.

If the vacuum level in a section has exceeded the pre-defined set-point, the vacuum protection system will immediately and simultaneously close the appropriate vacuum valves, trip the SR RF system, and close the photon shutters protecting the valves.

The priority 1 vacuum protection system is connected to the SR vacuum protection system. Bad vacuum in the first front end section will cause valves in the connected SR cells to close, as well as a SR RF trip. Bad vacuum in an adjacent SR cell will cause one or more of the FE valves to close.

The priority 1 vacuum protection system is connected to the beamline vacuum protection system. The beamline provides a 'Beamline Vacuum Status' to interlock the last two valves in the FE.

2.3.3.2 Priority 2 Vacuum Protection

In addition to the standard priority 1 vacuum protection, the front end vacuum protection implements a priority 2 vacuum protection. The purpose of the priority 2 protection is to prevent FE vacuum from tripping the SR RF.

If the vacuum level in a front end vacuum section exceeds the Priority 2 threshold (typically $5x10^{-7}$Torr), the front end will by systematically shut-down without tripping the SR RF. First, IDs are disengaged, then appropriate photon shutters are closed, and finally appropriate vacuum valves are closed.

The CCGs provide an analogue output of the vacuum level which is monitored by the machine protection PLC. If any of the cold cathode gauges indicate a vacuum level above the priority 2 level, the protection system will systematically remove the photon beam, then close the valves. The photon beam will be removed by closing the appropriate photon shutter, or disengaging the IDs. The SR RF will not be tripped at the priority 2 vacuum level.

2.3.3.3 Fast Vacuum Protection

Information from other synchrotron facilities indicate that the shock wave from a break in vacuum propagates at 1 m/ms. There is a higher risk of loss of vacuum on beamlines which have a 'windows.' i.e. hard x-ray beamline. The CLS standard vacuum components include MKS Cold Cathode Gauges (CCG) which have a response time of ~50ms, and VAT remote vacuum valves (VVR) also which also have a similar response time of ~50ms. Therefore, use of the standard vacuum components will not protect the machine from a shock wave originating at the beamline.

The VAT fast vacuum valve system closes fast valves (VVF) in 4~10ms. The fast valve system consists of a high voltage VAT cold cathode gauge (CCG), fast (non-sealing) valve and a system controller. With the CCG placed a sufficient distance from the fast valve, the system will be able to detect a vacuum breach and close the fast valve to prevent the shock wave from damaging upstream SR components. The trip level for the VVF system is set at $5x10^{-6}$Torr.

2.3.3.4 RGA Vacuum Protection

The Residual Gas Analyzer (RGA) is simply a mass spectrometer which is used to measure the partial pressure of the residual gas species remaining in the front end. The RGA has the ability to scan the partial pressure of 12 different species. The gases that are monitored will depend on the beamline and the science being conducted on that beamline. If the levels of any of the 12 gases exceeds a threshold level, a “Priority 1“ vacuum protection event will be initiated.

2.3.4 Components

2.3.4.1 Fast Vacuum Valve (VVF)

The Fast Vacuum Valve System is intended to protect the SR and front end from a vacuum breach in the beamline. The Fast Vacuum Valve System consists of the VVF, High Voltage Cold Cathode Gauge (CCG) and Controller. Note that the components of the Fast Valve system differ from the general use vacuum components used in other areas of the Machine.

a. The VVF is downstream of PSH1 and must be protected by PSH1. If the VVF is closed due to bad vacuum, the SR RF must be tripped.
b. When the Fast Valve is opened, it must be armed before it can be triggered to close. During the arming period (which can take up to 10 seconds) the remote vacuum valves will not be permitted to open. The Fast Valve has two limit switches to indicate whether the valve is Opened or Closed.
c. The VVF will only be *automatically* closed if the associated CCG detects bad vacuum.
d. If a vacuum problem is detected by other CCGs or IOPs the Machine Protection System will not trigger the VVF to Close. The rationale is:
    I. the control path from the other CCGs is slow in comparison to the integrated VVF system,
    II. there is little risk of a shock wave coming from the SR, and
    III. the VVF has a limited life of about 2000 closings before service is required.
    IV. The VVF does not seal, therefore is of little use when other valves are closed.
e. If vacuum problem is detected by the VVF system, all other VVRs in the Front-End will be closed.
f. The VVF triggering can be ‘Inhibited,’ to prevent the VVF from closing. This may be done by the Operator when the Front-End is undergoing maintenance.’
g. The VVF may be closed by the Operator when protected from the Beam (PSH1 is closed, or SR RF is Off).
h. In the event of a power outage, the VVF will Close.

2.3.4.2 Remote Vacuum Valves (VVR).

The Remote Vacuum Valves are vacuum tight valves which isolate vacuum sections. The VVRs have two limit switches to indicate the position of the valve, Opened or Closed. The FE VVRs are interlocked and controlled according to Priority 1 vacuum protection, and Priority 2 vacuum protection.

a. In the event of a Priority 1 vacuum trip, the Machine Protection System will:
    I. Trip the SR RF,
    II. Close PSH1, PSH2,

III. Close the Front-End VVRs, SR VVRs of adjacent cells.

b. In the event of a Priority 2 vacuum trip, the Machine Protection System will:
   I. Disengage IDs,
   II. Close PSH2,
   III. Close PSH1 after IDs are disengaged,
   IV. Close the Front-End VVRs, when the protecting PSH is closed.
c. VVRs may be closed by the Operator when protected from the beam.

2.3.4.3 Secondary Photon Shutter (PSH1) – Dual ID Front-End

There are two types of Secondary Photon Shutters which depend on the type of Front-End in which they are installed. PSH1 is located upstream of all other Front-End components which can be inserted into the beam path. PSH1 provides protection for the first VVR and the VVF.

In the Dual ID Front-End, PSH1 stops stray Bending Magnet radiation. Due to space limitations in the Duplex ID Front-End, PSH1 is smaller than the Primary Photon Shutter and not able to withstand the radiation generated by Insertion Devices. Therefore, VVR1 and the VVF cannot be closed when there is radiation generated from Insertion Devices.

a. PSH1 has two (2) limit switches to indicate the position of the PSH, IN (Closed) or OUT (Open). Closing time is estimated to be in the range of 1/2 a second.
b. In a Duplex ID Front-End, PSH1 protects the first VVR and the VVF from Bending Magnet radiation.
c. If a priority 1 vacuum problem is detected in the Front-End, the Machine Protection System will simultaneously trip the SR RF, close PSH1, and close the appropriate vacuum valves. The soft SR RF is designed to trip within 1ms, so PSH1 will not be damaged from ID generated radiation.
d. If a priority 2 vacuum problem is detected in the FE, PSH-1 will be closed after IDs have been disengaged. The SR RF will not be tripped. Vacuum FE valves will be closed after PSH-1 has successfully been closed.
e. If PSH2 fails to Close when required, IDs will be disengaged, then PSH1 will be closed.
f. If PSH1 is Closed, the Machine Protection System will not permit the SR RF to run until PSH1 has been Opened, or the Insertion Devices have been disengaged.
g. If PSH1 is Closed and the SR RF is On, the Machine Protection System will prevent the Insertion Devices from being engaged.
h. PSH1 is permitted to CLOSE if:
   i. SR RF is OFF;
   ii. SR RF is ON and both Insertion Devices are OUT.
i. PSH1 is permitted to OPEN if:
   i. SR RF is OFF;
   ii. SR RF is ON, VVR1 and VVF are open, PSH2 and downstream components are in a protected state.
j. If a problem with a photon shutter cooling water (flow, pressure, temperature) is detected, the Machine Protection System will trip the SR RF until the problem has been corrected.

2.3.4.4 Secondary Photon Shutter (PSH1) – Single ID / BM Front-End

In the Single ID and Bending Magnet Front-Ends, PSH1 is identical to PSH2 and can withstand the radiation generated by the Insertion Devices. PSH1 can be closed when there is radiation generated by Insertion Devices.

a. PSH1 has two (2) limit switches to indicate the position of the PSH, IN (Closed) or OUT (Open). Closing time is estimated to be in the range of 1/2 second.
b. In a Single ID / Bending Magnet Front-End, PSH1 protects the first VVR, VVF and downstream components from radiation generated by Insertion Device and Bending Magnets.
c. If a priority 1 vacuum problem is detected in the Front-End, the Machine Protection System will simultaneously trip the SR RF, close PSH1, and close the appropriate vacuum valves.
d. If a priority 2 vacuum problem is detected in the FE, PSH-1 will be closed but the SR RF will not be tripped. FE vacuum valves will be closed after PSH-1 has successfully been closed.
e. If PSH2 fails to Close when instructed, PSH1 will be closed.
f. PSH1 is permitted to CLOSE at any time.
g. PSH1 is permitted to OPEN PSH1 if:
    i SR RF is OFF;
    ii SR RF is ON, VVR1 and VVF are open, PSH2 and downstream components are in a protected state.
h. If a problem with a photon shutter cooling water (flow, pressure, temperature) is detected, the Machine Protection System will trip the SR RF until the problem has been corrected.

2.3.4.5 Primary Photon Shutter (PSH2)

The Primary Photon Shutter stops radiation from Insertion Devices and Bending Magnets from damaging downstream components including the safety shutters, vacuum valves, and beamline optical components. The Primary Photon Shutter is identical in all Front-Ends.

a. PSH2 has two (2) limit switches to indicate the position of the PSH, IN (Closed) or OUT (Open). Closing time is estimated to be in the range of 1/2 second.
a. The PSH2 must be closed in order for the Safety Shutter to be closed.
b. If a priority 1 vacuum problem is detected in the Front-End, the Machine Protection System will simultaneously trip the SR RF, close PSH2, and close the appropriate vacuum valves.
c. If a priority 2 vacuum problem is detected in the Front-End, the Machine Protection System will close PSH2, and close the appropriate vacuum valves.
d. If the SR RF is ON, the Machine Protection System will not permit PSH2 to be opened until the SSH and all downstream Vacuum Valves have been Opened.
e. If a problem with a photon shutter cooling water (flow, pressure, temperature) is detected, the Machine Protection System will trip the SR RF until the problem has been corrected.

2.3.4.6 Safety Shutters (SSH 1 & 2)

The Safety Shutters (SSH) are controlled by the Personnel Safety System. The Photon Shutter(s) are intended to protect the Safety Shutters from the Synchrotron Radiation.

The radiation damage will cause severe out-gassing resulting and may permanently damage the SSH tungsten block.

a. When the SR RF is ON, the SSH may not be Closed until the PSH2 is Closed.

b. If a problem with SSH cooling water (flow, pressure, temperature) is detected, the Machine Protection System will trip the SR RF until the problem has been corrected.

2.4 SERVICES

2.4.1 Cooling Water

Low conductivity water is used to cool some front end and beamline components (as identified on the P&I drawings). The water flow rate, pressure, and temperature of the cooling water returning from each of these components is monitored. If any problem is detected and sustained for a short period of time (5 – 30 sec), the Machine Protection System will take the actions indicated in the tables below. If the SR RF is tripped, it may be restarted if the problem is corrected, or the source of heat is removed by disengaging IDs.

Table 5 – Cooling Water Logic Duplex ID Front-Ends

Problem Component	Action	Comment
Front-End Header	Trip the SR RF	Upstream of PSH2
Pre-Fixed Mask 1		
Fixed Mask 1		
PSH1		
Fixed Mask 2	Trip the SR RF[1]	
PSH2		
Fixed Mask 3	Trip FE & Beamline (Close PSH2)	Protected by PSH2

1 – SR RF may be allowed to run once the source of heat is removed by disengaging IDs and inserting PSH1.

Table 6 – Cooling Water Logic Single ID & Bending Magnet Front-Ends

Problem Component	Action	Comment
Front-End Header	Trip the SR RF	Upstream of PSH1
Pre-Fixed Mask 1		
Fixed Mask 1		
PSH1		
Fixed Mask 2	Trip FE & Beamline (Close PSH1, PSH2)	Protected by PSH1
PSH2		
Fixed Mask 3	Trip FE & Beamline (Close PSH2)	Protected by PSH2

2.4.2 Liquid Nitrogen

Not used.

2.4.3 Liquid Helium

Not used.

2.4.4 Titanium Sublimation Pumps (TSP)

A titanium sublimation pump (TSP) is connected to the vacuum chamber surrounding the primary photon shutter (PSH1). When the PSH1 closes and the photon beam hits the shutter, the shutter begins to outgas. The longer the shutter has been open and not exposed to the photon beam the more it will outgas. In an attempt to reduce the outgassing, the TSP could be run prior to closing the shutter. A schedule or a set of conditions for using this pump will need to be developed. Consideration will need to be made as to how often the pump is run as the TSP filaments have only a 12 hour lifetime.

3.0 USER'S GUIDE

3.1 SOFTWARE INTERFACE

A general arrangement drawing of the Front-End is used as a map to the Front-End. The status and control of all the valves and shutters (except for the Safety Shutter control) are achieved through this interface. Whether a device is in a “protected” or “unprotected” state is indicated on the control screen. The vacuum levels for each section are also indicated on the control screen.

3.2 SAFETY SHUTTER CONTROL

The Safety Shutter (SSH) is controlled at the pOE ACIS lock-up panel. The SSH can only be opened after the pOE lockup has been successfully completed.

4.0 DESIGN

4.1 MACHINE PROTECTION

Machine protection for each Front End is implemented using a dedicated Telemecanique Momentum PLC. The PLC is located on top of the SR1 tunnel along with the Front-End vacuum equipment.

For fast vacuum protection a VAT Series 75 Fast Valve and High Voltage Vacuum sensor is used.

Redundant vacuum valve interlocks are implemented in hardware and software. The interlocks are provided to the Front-End, SR vacuum valves. The hardware system utilizes one set of dry contacts provided by the vacuum equipment (CCG, IOP, RGA) driving relays. The software interlocks utilizes a second set of dry contacts provided by the vacuum equipment monitored by the front end Telemecanique Momentum PLC.

Additional monitoring and control of the vacuum pump powers supplies and gauging is provided over RS-232 using MOXA IOC computers[1]

[1] Older installations (Phase 1) use EROC computers. These are being phased out.

4.2 DIAGNOSTICS

4.2.1 X-ray BPMs

Front End X-ray Beam Position Monitors (FE XBPM) provide spatial coordinates of the first moment of the photon beam intensity prior to interaction with beamline optics. The monitors on the ID beamlines consist of gold coated chemical vapour deposition diamond blades housed within OFHC copper modules mounted onto the exit aperture of a fixed mask. For the bend magnet lines a specially constructed vacuum chamber houses a large OFHC copper aperture containing molybdenum blades. To determine the position of the photon beam, the blades of the XBPM are situated within the VUV and soft x-ray portion of the synchrotron radiation. Through the mechanism of photoemission a micro-ampere electrical current is generated on the blades. By calculating the difference over sum of the currents measured by picoammeters, it is then possible to determine the photon beam position. Each of the XBPM units is designed to achieve sub-micron spatial resolution of synchrotron beam motion.

4.2.2 Surface Mount RTDs

When commissioning a new front end design surface mount RTDs (PT100) may be placed on the Front-End fixed masks (e.g. FM1) and other Front-End components. These are temporary in nature and not used for interlock functions. A portable temperature monitoring system using National Instruments FieldPoint has been developed for this purpose.

5.0 REFERENCES

1. Booster/Storage Ring/Beamlines Access Control and Interlock System (ACIS) PLC Component Manual", 7.9.39.4

6.0 APPENDIX A: SUB-COMPONENT MANUALS