CEBAF 12 GeV Personnel Safety Systems – Preliminary Design

1 CEBAF at 12 GeV

The CEBAF upgrade to 12 GeV will include extending the present CEBAF safety systems in the accelerator and add a “Tagger/Hall D” PSS segment. This note describes the intended equipment and modifications to the existing JLab PSS.

2 Introduction

Personnel Safety Systems (PSS) are engineered controls designed to protect personnel from hazards created by accelerator operation. The personnel protection functions mitigate hazards including prompt ionizing radiation, non-ionizing radiation, exposed magnet leads, and oxygen deficiency. JLab Prompt Radiation Control Policy\(^a\) requires that personnel are protected from prompt ionizing radiation and that personnel are not allowed access to areas where prompt ionizing radiation may be present.

PSS systems associated with the 12GeV upgrade will be functionally similar to those presently used in the CEBAF accelerator yet use available safety certified hardware. The CEBAF accelerator was the first large accelerator project to use industrial programmable logic controllers (PLCs) as safety system logic interlock controls. Since the initial CEBAF design and commissioning, a new class of PLCs designed and certified specifically for use in safety applications is available. The 12GeV upgrade and Hall D safety interlock systems will use redundant safety PLCs as the backbone of the PSS. This will not only increase the safety reliability of the system, it will also increase the overall availability of the accelerator. The JLab Safety Systems Group will take advantage of the experience and lessons learned from the Large Hadron Collider project at CERN, which is presently using hardware similar to that planned for the CEBAF 12 GeV upgrade safety systems, and from recent projects like the SNS at Oakridge and LCLS at SLAC.
3 Assumptions

3.1 Machine Configuration
The 12GeV CEBAF machine configuration is assumed to be:

- 5 and one half passes
- 5 additional cryomodules in each linac
- An additional arc line in the west arc
- Tagger and Hall D buildings located at the northeast end of the North Linac
- There are sufficient inter-building conduits and cableways to support PSS isolated conduit and cabling

4 Scope of work

4.1 Design and Development
The design of the 12 GeV upgrade safety systems will follow the standards of practice set out in international standards IEC61511 and IEC61508. These standards represent accepted good practice for the design and implementation of safety systems. The design will include all steps necessary to produce a baseline design and cost information for the safety systems. The 12GeV CEBAF PSS systems will be designed to meet the applicable portions of the following design basis documents:

- IEC61508 Parts 1-3
- IEC61511 Parts 1-2
- DOE Accelerator Order 420.2b
- DOE Accelerator Order 420.2b Guidance
- NCRP Report 88 Radiation Alarms and Access Control Systems
- ICRP Report 188 Radiological Safety Aspects for the Operation of Electron Linear Accelerators
- NFPA 70E Standard for Electrical Safety in the Workplace, 2004 Edition
- ANSI/ISA RP92.2 Operation and Maintenance of Oxygen Monitoring Systems
4.2 Installation
The 12 GeV PSS upgrade will involve the following changes and modifications to the CEBAF Personnel Safety System:

4.2.1 North Linac
- Upgrade the North Linac Quantum PLC drop to the Modicon Quantum family.
- Add a beam stopper suite between station number 1590-NS and 1620-NS composed of:
  - PSS Beam Current Monitors
  - Beam Diffuser
  - Two beam stoppers
- Add 5 RF Interface Chassis for RF zones 1L22-1L26
- Add magnet box supply interface for Arc 10
- Add 3 Run/Safe Boxes to North Linac Transport Tunnel Extension
- Add Interlocked Door or Gate at base upper section of Tagger Transport Tunnel
- Extend the North Linac ODH alarm system to the North Stub.
- Extend the North Linac Public Address System to the North Stub.

4.2.2 South Linac
- Upgrade the South Linac Quantum PLC drop to the Modicon Quantum family.
- Add 5 RF Interface Chassis for RF zones 2L22-2L26

4.2.3 Tagger/Hall D
- Add 3 PSS Racks to Hall D
- Add 3 PSS Racks to Tagger Building
- Install redundant safety PLC master drop in the Machine Control Center (MCC)
- Install Redundant Safety PLC remote I/O in Hall D
- Install Redundant Safety PLC remote I/O to Tagger building
- Install Redundant Safety PLC remote I/O in the Injector (Hall D drop)
- Triplicate (2003) DC current monitors to Tagger current bus
- Triplicate (2003) DC current monitors to North stub vertical bend bus
- One (redundant) PSS Beam Current Monitor to the Hall D Photon Line
- High Tc Permanent Magnet in the Hall D photon line
• 10 run/safe boxes to Hall D and Tagger Building
• Add magnet interface in Tagger Building for Hall D Arc Dipoles
• Add access control point to Tagger Building and Hall D
• Add Oxygen Deficiency Monitoring and Alarm System to Hall D
• Install Public Address system in Tagger Building and Hall D
• Install Emergency Crash EStop in Hall D control room.

4.3 Training
Existing PSS Operator training material will be updated to incorporate additional equipment and operational modes.

5 Description of work

5.1 New modes
Even though the RF separator and beam transport systems will support simultaneous operation of only three endstations at one time, the PSS logic must be complete and deterministic for all possible combinations of beam termination points. Therefore the complexity of the PSS for endstation operating modes is increased from 10 to 19 possible modes. Each mode is determined by the status of critical devices as well as PSS operator controls.

a JLab Prompt Radiation Control Policy, EH&S Manual 6310-T2
<table>
<thead>
<tr>
<th>PSS Mode</th>
<th>Mode Description</th>
<th>Injector</th>
<th>North Linac</th>
<th>South Linac</th>
<th>BSY</th>
<th>Hall A</th>
<th>Hall B</th>
<th>Hall C</th>
<th>Hall D</th>
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<tbody>
<tr>
<td>1</td>
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<td>Beam to Halls A, B, C, D</td>
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Table 1. Allowed Beam Permit Modes for 12 GeV Upgrade Operations.
Shaded areas represent machine segments that must be in “Beam Permit” for a given operational mode.

Table 1 12GeV Operating Modes

1 This mode is for ≤ 500keV beam setup only.
2 This mode is used for low level beam operations up to the injection point of the North Linac. There is no beam in the linac.
3 This mode allows one pass beam from the north linac only to Hall D. It is used for tune-up, accelerator physics, and commissioning.
4 Although it is not functionally necessary to lock up the BSY for Beam to Hall D, there is no radiological isolation between the South Linac and BSY. Therefore the BSY must be locked up in order to transit beam through the South Linac.
5 Although this mode is supported by the PSS, it is not physically possible to send beam to all four endstations at once.
5.2 Technical Approach
The 12GeV upgrade Personnel Safety Systems (PSS) are built on the technology used in the present systems used throughout the JLab campus. Programmable Logic Controllers (PLCs) monitor interlock and status indicators on all access control and interlocked equipment. Advances in PLC technology plus the implementation of international standards for the use of programmable systems in safety applications has led to the development of “safety” PLCs designed and certified for use in safety systems. A master safety PLC will be installed in the machine Control Center (MCC) building. Safety rated (IEC61508) remote I/O will be used in the Tagger building, Hall D, and the Injector Service Building (Figure 1.)

Although in theory the reliability of the safety PLC is such that one Safety PLC could be used, i.e. no need for PLC redundancy, the system will be implemented fully redundantly in order to gain experience with the new technology. The Safety PLCs incorporate extensive self test as well as field wiring diagnostics. All detected unsafe failure modes result in the system shutting down hazardous equipment. An undetected unsafe failure of one leg of the system will not affect the ability of the second system perform the safety function.
Figure 1  PSS Equipment Locations
5.2.1 Critical Devices

Devices that isolate an occupied area from a beam operations area are termed “Critical Devices.” It is JLab policy to use at least three critical devices, implemented by at least two distinct technologies to protect personnel in occupied areas downstream of beam operations. The standard suite of critical devices includes two beam stoppers and control of magnets that bend the beam in the direction of the downstream target.

No device short of a full power 1 MW beam dump is designed to take the full CEBAF beam power indefinitely. The beam stoppers are designed such that a beam burn through will rupture an internal nitrogen filled chamber, spoiling the vacuum and dispersing the beam within the tunnel. Of course, such drastic measures are only required for the most catastrophic of circumstances. It is therefore necessary to take steps to ensure that beam on the beam stoppers is removed before catastrophic damage to the stopper occurs. JLab has solved this problem using two approaches.

1.) All beam stoppers are protected by a PSS beam current monitoring system. If beam impinges on the beam stopper the BCM system will shut off the beam in less than 1 millisecond.

2.) All beam stoppers are protected by a beam diffuser. The beam diffuser is a thin cylinder designed to disperse a tightly focused beam in order to spread the beam power over a larger surface area on the stopper face.

The existing beam diffuser and the beam current monitor are designed to operate with 12GeV beam. No design changes are required. Figure 2 shows a preliminary layout of the Tagger/Hall D critical devices.

5.2.2 Beam Containment

It is critical that beam transport from the entrance of the Hall D vertical bend to the Tagger dump be monitored to ensure that errant beam does not create a radiation area or high radiation area outside of the concrete shielding. It is also vital that beam entering the Tagger area not transport downstream to Hall D.

A new beam transport monitor (Figure 3) will be designed that will measure the DC current in the upward vertical bend magnets and the Tagger downward vertical bend magnets. The
currents must remain proportional within a given tolerance or a fault will be declared and the PSS will shut down the beam. The BTM will include both warning and trip thresholds.
Figure 2  Tagger/Hall D  Critical Device Layout
Figure 3. Beam Transport Monitor Functional Diagram
5.2.3 Interdependencies with other systems

The PSS systems interface with the magnet, RF, and electron gun power supplies. The PSS provides a “Permit” to operate signal and each device sends an on/off status signal back to the PSS. In the 12GeV upgrade, these interfaces remain functionally unchanged. In addition to the interface with power supplies, the Hall D beam line is equipped with a beam diffuser and two beam stoppers. These devices are designed and fabricated by the mechanical engineering group to safety system group (SSG) specifications.

<table>
<thead>
<tr>
<th>System</th>
<th>Design Responsibility</th>
<th>Owner</th>
<th>PSS Interface</th>
<th>Change from present systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>RF High Power Amplifier Power Supply</td>
<td>Electrical Engineering Group</td>
<td>EES</td>
<td>Permit, Emergency OFF, Ready, OFF/Safe</td>
<td>None</td>
</tr>
<tr>
<td>Magnet Box Power Supply</td>
<td>Electrical Engineering Group</td>
<td>EES</td>
<td>Permit, OFF/Safe</td>
<td>New supplies will be controlled through a dedicated PSS AC contactor</td>
</tr>
<tr>
<td>Beam Stopper</td>
<td>Mechanical Engineering Group</td>
<td>SSG</td>
<td>Permit, Status, Pressure</td>
<td>None</td>
</tr>
<tr>
<td>Beam Diffuser</td>
<td>Mechanical Engineering Group</td>
<td>SSG</td>
<td>Permit, Status, Pressure</td>
<td>None</td>
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<tr>
<td>EPICS Software</td>
<td>Controls Software</td>
<td>SSG</td>
<td>Secure Ethernet</td>
<td>Drivers for communication with a new class of PLC will be required.</td>
</tr>
<tr>
<td>Controlled Area Radiation Monitoring</td>
<td>Radiation Control</td>
<td>Radiation Control</td>
<td>Contact Closure – Dose Rate &gt; Limit</td>
<td>None</td>
</tr>
</tbody>
</table>

Table 2 PSS Interfaces
Interfaces with non-PSS equipment will follow the existing system model of using interface chassis for isolation. The isolation provides protection against equipment induced common mode errors as well as keeps the two PSS chains electrically isolated.