Beam Instrumentation

Functional Requirements Specification

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Document Approval

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Revision History

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|  | 8/18/2021 | Initial Draft |
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# PURPOSE

A Functional Requirements Specification (FRS) document describes the project needs and/or requested behavior of a system or component. The FRS typically outlines what is needed by the end user as well as the requirements and requested properties of inputs and outputs. The FRS specifies the functions that a system or component must perform and establishes consensus among stakeholders on what the system is expected to provide.

# SCOPE

This FRS addresses the functional requirements of the beam diagnostics instrumentation from the PIP-II warm front-end through the superconducting Linac and 800 MeV transport line into the Booster ring. The various beam instrumentation and diagnostics systems will characterize and monitor the beam parameters and the performance in all PIP-II sub-accelerators from commissioning through operations.

# KEY ASSUMPTIONS

BI systems shall also abide by requirements outlined in FEM [1]. Key cost, schedule, technical and programmatic assumptions are provided in PIP-II Project Assumptions [8]. Additional assumptions include the following:

* Alignment, welding, and vacuum-work in the enclosure will be provided during BI installation. Aside from the fiducial markers, functional requirements for such services are not covered in this document.
* Vacuum lab infrastructure, such as cleanrooms and pumping carts, shall be provided. Functional requirements for such facilities and equipment are not covered in this document.
* AC power, ground, cable trays, conduits and penetrations, and relay racks shall be provided to BI system. Functional requirements for such systems are beyond the scope of this document.
* Event-based triggers, event-encoded clock signals, and RF signals, and Ethernet network infrastructure will provide for accessible and usable connections to BI systems. The function requirements for those signals are beyond the scope of this document.
* Functional requirements for capabilities for the client applications in Control System is beyond the scope of this document.

# REFERENCE

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| --- | --- | --- |
| # | Reference | Document # |
| 1.
 | [Fermilab Engineering Manual](http://directorate-docdb.fnal.gov/cgi-bin/RetrieveFile?docid=34) (FEM) | - |
| 1.
 | [Fermilab Environmental Safety and Health Manual](http://eshq.fnal.gov/manuals/feshm/) (FESHM) | - |
| 1.
 | [Fermilab Radiological Control Manual](https://eshq.fnal.gov/manuals/frcm/) (FRCM) | - |
| 1.
 | [Fermilab Quality Assurance Manual](https://eshq.fnal.gov/manuals/qam/) (QAM) | - |
| 1.
 | PIP-II Procurement Plan | PIP-II docDB 522 |
| 1.
 | PIP-II 121.03 Accelerator Systems Quality Assurance (QA) Plan | PIP-II docDB 4805 |
| 1.
 | PIP-II Beam Instrumentation Quality Control (QC) Plan | PIP-II docDB xxxx |
| 1.
 | PIP-II Project Assumptions | PIP-II docDB 144 |
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# ACRONYMS

|  |  |
| --- | --- |
| BCM | Beam Current Monitor |
| BI | Beam Instrumentation |
| BLM | Beam Loss Monitor |
| BPM | Beam Position Monitor |
| BProM | Beam Profile Monitor |
| BTE | Beam Transverse Emittance |
| BTP | Beam Transverse Profile |
| EPDM | Engineering Process Document Management |
| FEM | Fermilab Engineering Manual |
| FESHM | Fermilab ES&H Manual |
| FRCM | Fermilab Radiological Control Manual |
| FQAM | Fermilab Quality Assurance Manual |
| FRS | Functional Requirements Specification |
| L2 | WBS Level 2 |
| L3 | WBS Level 3 |
| LEBT | Low Energy Beam Transport |
| MEBT | Medium Energy Beam Transport |
| MPS | Machine Protection System |
| PIP-II | Proton Improvement Plan II Project  |
| QA | Quality Assurance |
| QC | Quality Control |
| RWCM | Resistive Wall Current Monitor |
| TC | Teamcenter |
| WBS | Work Breakdown Structure |
| WFE | Warm Front End |

# FUNCTIONAL REQUIREMENTS

For startup and initial beam commissioning, at a minimum, beam instruments are required to observe beam position and phase, beam losses, beam profiles, and beam current and intensity. Besides these core beam instrumentation systems, additional beam diagnostics are needed to characterize beam emittance, transverse beam halo, bunch-by-bunch chopping efficiency and advanced beam emittance measurements.

Table ‑. General Requirements

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| --- | --- |
| Requirement # | Requirement Statement |
|  F-121.3.09-A001 |  The BPM beam instrumentation system shall be capable of measurements of short commissioning beam pulses as well as nominal length operational beam pulses, for pulses repetition rates up to 20 Hz. |
|  F-121.3.09-A002 |  The BCM beam instrumentation system shall be capable of measurements of short commissioning beam pulses as well as nominal length operational beam pulses, for pulse repetition rates up to 20 Hz. |
|  F-121.3.09-A003 | The BLM beam instrumentation system shall be capable of measurements of short commissioning beam pulses as well as nominal length operational beam pulses, for pulse repetition rates up to 20 Hz. |
|  F-121.3.09-A004 |  The BPM system shall measure the average beam transverse position, relative beam intensity and relative beam phase at each focusing element for the MEBT, Linac and transport line for each beam pulse. |
|  F-121.3.09-A005 |  The BPM system shall measure the beam energy in the transport line dispersion region for every beam pulse. |
|  F-121.3.09-A006 |  The BLM system shall measure relative beam loss for each beam pulse in the Linac and transport line. |
|  F-121.3.09-A007 |  The BLM system shall provide relative beam loss information for each beam pulse to the MPS. |
|  F-121.3.09-A008 |  Noninvasive BCM system, except RWCM, shall measure the average beam current for each beam pulse in the LEBT, MEBT, Linac and transport line. |
|  F-121.3.09-A013 |  BCM systems with invasive pickups shall measure the instantaneous beam current for each beam pulse in the WFE, relative to an adjustable trigger. |
|  F-121.3.09-A014 |  BCM systems with RWCM pickups shall provide bunch shape information. |
|  F-121.3.09-A009 |  The BCM system shall provide signals for differential beam current measurements in the MPS for each beam pulse. |
|  F-121.3.09-A010 |  The BTP system shall measure beam average transverse profiles when requested. |
|  F-121.3.09-A011 |  The BTE system shall measure the beam transverse emittance when requested. |
|  F-121.3.09-A012 |  The warm BPM pickups in the MEBT and Linac shall be pinned and mounted directly to the steel of the focusing quadrupole magnets. |

Table ‑. Alignment Requirements

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| --- | --- |
| Requirement # | Requirement Statement |
|  F-121.3.09-B001 |  Alignment services shall provide as-found alignment measurements to locate the BPM position and orientation in the MEBT and Linac. |
|  F-121.3.09-B002 |  The transfer line BPM pickups shall have fiducials to allow for proper alignment to the mechanical center of the beam pipe by alignment services. |
|  F-121.3.09-B003 |  The LEBT BTE detectors in their ion source vacuum enclosures shall have internal and external fiducials to allow for proper alignment by alignment services |
|  F-121.3.09-B004 |  The MEBT BTE detectors in their vacuum enclosures shall have internal and external fiducials to allow for proper alignment to the mechanical center line of the beam pipe by alignment services. |
|  F-121.3.09-B005 |  The MEBT and transfer line wire scanner-based BTP monitors in their vacuum chambers shall have internal and external fiducials to allow for proper alignment to the beam pipe mechanical centers by alignment services. |
|  F-121.3.09-B006 |  The Linac laser-based BTP monitors and optics shall have internal and external fiducials to allow for proper alignment to the mechanical center of the beam pipe by alignment services. |

# DESIGN & CONSTRUCTION STANDARDS

The following codes and standards in their latest edition shall be applied to the engineering, design, fabrication, assembly and tests of the given system:

* + - ASME B31.3 Process Piping
		- ASME Boiler and Pressure Vessel Code (BPVC)
		- CGA S-1.3 Pressure Relief Standards
		- NFPA 70 – National Electrical Code
		- IEC Standards for Electrical Components
		- UL61010 - Laboratory equipment
		- UL60950 - Computing/Telecommunication Equipment
		- ASHRAE - Datacenter Standards
		- IPC-JSTD-001 – Soldering
		- IPC2221 – PCB spacing and design
		- IPC-A-600 -- PCB acceptance and testing
		- IPC-A-610 -- Electronics assembly

In cases where International Codes and Standards are used, the BI system shall follow *FESHM Chapter 2110 Ensuring Equivalent Safety Performance Using International Codes and Standards* [3].

# SAFETY REQUIREMENTS

BI systems shall abide by FESHM [3] and FRCM [4] requirements, including but not limited to:

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| Pressure and Cryogenic Safety |
| * FESHM Chapter 5031 Pressure Vessels
* FESHM Chapter 5031.1 Piping Systems
* FESHM Chapter 5031.5 Low Pressure Vessels and Fluid Containment
* FESHM Chapter 5031.6 Dressed Niobium SRF Cavity Pressure Safety
* FESHM Chapter 5032 Cryogenic System Review
* FESHM Chapter 5033 Vacuum Vessel Safety
 |
| Electrical Safety |
| * FESHM Chapter 9110 Electrical Utilization Equipment Safety
* FESHM Chapter 9160 Low Voltage, High Current Power Distribution Systems
* FESHM Chapter 9190 Grounding Requirements for Electrical Distribution and Utilization Equipment
 |
| Radiation Safety  |
| * FRCM Chapter 8 ALARA Management of Accelerator Radiation Shielding
* FRCM Chapter 10 Radiation Safety Interlock Systems
* FRCM Chapter 11 Environmental Radiation Monitoring and Control
 |
| General Safety |
| * FESHM Chapter 2000 Planning for Safe Operations
* FESHM Chapter 10000 Material Handling and Transportation
 |

Any changes in the applicability or adherence to these standards and requirements require the approval and authorization of the PIP-II Technical Director or designee.

Additional safety requirements, which are not listed in the general list above or within Section 6 of this document, shall be elaborated in the TRS for the relevant BI system.

# QUALITY ASSURANCE PROVISIONS

At a minimum, BI systems shall adhere to FQAM [4], PIP-II Procurement Plan [5], PIP-II 121.03 Accelerator Systems QA Plan [6], and PIP-II Beam Instrumentation QC Plan [7]. Additional roles, provisions, and procedures are described in the TRS documents for each BI system.