PIP2IT High Energy Beam Transport

Technical Requirements Specification

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**Document Approval**

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# Purpose

A Technical Requirements Specification (TRS) is a means to communicate what type of system is being designed and implemented and lists the attributes of that system as it conforms to a specific metric.

A TRS describes the technical aspects that a system or component must fulfill, such as the technical characteristics, the performance requirements and/or the reliability requirements. TRS requirements may be derived from higher-level requirements in an FRS or ICD, or maybe proposed from the design process. TRS requirements may or may not be specific to a particular design concept.

# Introduction

The PIP-II Injector Test (PIP2IT) [1] is an integrated system test of the PIP-II front end [2]. It includes a warm front end, two cryomodules, and a High Energy Beam Transport line (HEBT) delivering the beam to a beam dump. The main goal for PIP2IT is to demonstrate the beam parameters that are required for PIP‑II nominal operation and described in Ref. [2]. Consequently, the HEBT must allow disposing of a kilowatt-grade beam and measuring its characteristics (e.g. transmission, emittance, energy). A list of the minimum set of beam measurements to be carried out in the HEBT can be found in Ref. [3].

This document describes the corresponding technical requirements for the HEBT.

# Scope

This specification describes the main technical requirements for the beam line downstream of the SSR1 cryomodule at PIP2IT. It does not address the requirements for individual components (e.g.: focusing elements, instrumentation) but defines the design envelope for these sub-systems.

# Acronyms

|  |  |
| --- | --- |
| BPM | Beam Position Monitor |
| CMTF | Cryomodule Test Facility |
| ES&H | Environment, Safety and Health |
| FAV | Fast-Acting vacuum Valve |
| FESHM | Fermilab ES&H Manual |
| FRCM | Fermilab Radiological Control Manual |
| HEBT | High Energy Beam Transport |
| HV | High Vacuum |
| HWR | Half Wave Resonator |
| L2 | WBS Level 2 |
| L3 | WBS Level 3 |
| MEBT | Medium Energy Beam Transport |
| MPS | Machine Protection System |
| NEG | Non-Evaporable Getter |
| PIP-II | Proton Improvement Plan II Project |
| PIP2IT | PIP-II Injector Test |
| PXIE | Project-X Injector Experiment\* |
| SNS | Spallation Neutron Source |
| SRF | Superconducting Radio-Frequency |
| SSR1 | Single Spoke Resonator type I |
| TC | Teamcenter |
| TRS | Technical Requirements Specification |
| UHV | Ultra-High Vacuum |

\* *Former name for PIP2IT, which still appears on older documents.*

# Reference

|  |  |  |
| --- | --- | --- |
| **#** | **Reference** | **Document #** |
| 1 | PIP-II Injector Experiment Functional Requirements Specification | ED0001223 |
| 2 | PIP-II Conceptual Design Report | ED0006203 |
| 3 | Measurements in the HEBT at PIP2IT | ED0008280 |
| 4 | PIP2IT Cave Shielding Assessment | - |
| 5 | PXIE Vacuum System Functional Requirements Specification | ED0004444 |

# Key Assumptions & Constraints

The PIP2IT cave is in its final configuration and both the HWR and SSR1 cryomodules are installed. The HEBT will be installed downstream of the SSR1 cryomodule. The HEBT is in a straight configuration and employs as many existing elements as possible. There is no element for longitudinal focusing.

The expected nominal beam parameters are listed in the table below.

**Table 1:** Nominal beam parameters in the HEBT.

|  |  |  |
| --- | --- | --- |
| **Parameter** | **Value** | **Unit** |
| Ion type | H- |  |
| Beam (kinetic) energy | 22 | MeV |
| Macro-pulse length | 0.55 | ms |
| Macro-pulse repetition rate | 20 | Hz |
| Frequency of bunches (within macro-pulse) | 162.5 | MHz |
| Beam current (averaged over 1 s) | 2 | mA |
| Nominal charge per bunch | 30 | pC |
| Beam size (X/Y) at the exit of the SSR1 cryomodule (rms) | 2.2 | mm |
| Bunch length at the exit of the SSR1 cryomodule (rms), *z* | 20 | ps |

The maximum total length of the HEBT is dictated by the space available between the end of the SSR1 cryomodule and the wall of the exit labyrinth (~6m), including an egress path behind the dump.

The maximum average beam power shall not exceed 700 W, in accordance with the assumptions contained in the radiation shielding assessment of the PIP2IT cave [4].

# Requirements

## Beamline requirements

The beamline centerline shall be 1.3 m off the floor. All hardware will be mounted on stands bolted to the floor of the PIP2IT cave. Beamline components shall be referenced off-line for alignment with respect to the beam line centerline unless physically constrained by adjacent elements (e.g.: in-flange current transformer). Alignment tolerances are set at the component level.

## Beam parameters

The HEBT shall accommodate a range of beam parameters around the nominals listed in Table 1. Those are summarized in the table below.

**Table 2:** Range of beam parameters that the HEBT shall be able to accommodate.

|  |  |  |
| --- | --- | --- |
| **Parameter** | **Value** | **Unit** |
| Beam (kinetic) energy | 10 - 25 | MeV |
| Macro-pulse length | 5 - 550 | s |
| Macro-pulse repetition rate | 1 - 20 | Hz |
| Beam current (averaged over 1 s) | 0.2 - 2 | mA |
| Charge per bunch | 3 - 60 | pC |

In addition, for macro-pulses longer than 20 s, the HEBT shall be able to ensure that the beam size at the entrance of the beam dump is large enough (hence, minimizing the power density of the beam) to operate without deteriorating the beam dump.

## Radiation shielding requirements

Implementation of proper radiation shielding (in particular close to the beam dump) shall ensure that the CMTF high-bay floor is a controlled area with no occupancy restrictions in all beam regimes in accordance with the beam operation scenarios considered in the PIP2IT Cave Shielding Assessment [4].

Access to the rooftop of the PIP2IT cave may have an occupancy restriction but there will be no provision for interlocking that area.

Activation of the beamline components shall be monitored during operation to ensure safe and inexpensive handling during maintenance and eventual dismounting. The beam duty factor and/or operation time may be limited if excessive activation is observed. Note that the beam dump will reside inside its own radiation shielding enclosure, which will serve as a temporary coffin during its cool down.

## Vacuum requirements

The HEBT vacuum requirements shall abide by the PIP2IT Vacuum System FRS [5], which sets general limits for the vacuum pressure along the PIP2IT beam line. Thus, the vacuum near the SSR1 cryomodule isolation valve shall reach <10-9 torr with the valve closed and whether or not the cryomodule is at its operating temperature (i.e. 2K). The vacuum pressure just downstream of the isolation valve shall be measured and monitored.

The HEBT shall be UHV/particle-free from the isolation valve on the SSR1 cryomodule to a minimum distance of 5 m beyond the location of a fast-closing vacuum protection valve (a.k.a. Fast-Acting Valve). All beam line components shall be qualified as particle-free in their design and assembly shall follow particle-free handling best practices. Turbomolecular pumps shall not be used as vacuum pumping devices (ion pumps, NEG pumps or cryopumps are satisfactory), except for initial pump down. In the latter case, they must be isolated from the beam line afterwards.

The beamline shall be bake-out compatible to a minimum of 100°C with the possible exception of the beam dump.

In addition to the SSR1 cryomodule’s isolation valve, the HEBT shall incorporate at least one remote-controllable (slow) gate valve and a fast-closing vacuum protection valve upstream of the latter with a corresponding system of sensors and controls. Vacuum valves are expected to be standard items commercially available and in general use at Fermilab. Typical requirements are shown in the table below:

**Table 3:** Minimum vacuum valves requirements

|  |  |  |
| --- | --- | --- |
| **Parameter** | **Value** | **Unit** |
| Gate/isolation valve closing time | <0.7 | s |
| Fast-Acting Valve (FAV) closing time | <10 | ms |
| Maximum leak rate (body) | 10-10 | Torr l s-1 |
| Maximum leak rate (seal) | 10-9 | Torr l s-1 |

No insertable devices shall be installed between the SSR1 cryomodule and the Fast-Acting Valve and no closer than 1 m away from the SSR1 isolation valve.

The design of the HEBT vacuum enclosure shall allow for venting the system without external contamination. Slow pump downs/back-fills shall be done at a maximum gas flow of 250 sccm when the pressure in the vacuum enclosure is between 1 torr and atmosphere.

## Diagnostics requirements

The diagnostics to be installed in the HEBT shall allow carrying out the measurements listed in Ref. [3] for any train structure satisfying Table 2. They shall be cleaned to particle-free standards before installation in the beamline.

A subset of the signals provided by various instruments (e.g. current monitors) shall be routed to the Machine Protection System (MPS) to prevent beam-induced damages during commissioning or in case of failures of critical sub-systems. The determination of thresholds and limits for the MPS is beyond the scope of this document.

## Controls and communication requirements

All components shall be remotely controllable via Fermilab’s Controls System, including but not limited to, focusing elements and dipole correctors power supplies, insertion devices motion, triggering and data acquisition. Instrumentation signals shall be remotely readable, including but not limited to Beam Position Monitors (BPM), beam current monitors, beam loss monitors (if applicable), protection electrodes current monitors (if applicable), emittance monitor.

## Servicing and test-stand transition requirements

The HEBT implementation shall be compatible with conversion of PIP2IT into a test-stand for the SSR and 650-MHz cryomodules. Specifically, components shall have a way to be either removed from the cave (with appropriate radiological controls) or left in place without interfering with the test-stand operations.

## Safety requirements

The HEBT shall abide by all Fermilab ES&H (FESHM) and all Fermilab Radiological Control Manual (FRCM) requirements, in particular, FESHM Chapter 5033 Vacuum Vessel Safety, FRCM Chapter 8 ALARA Management of Accelerator Radiation Shielding and FRCM Chapter 11 Environmental Radiation Monitoring and Control.