Measurements to be conducted in the High Energy Beam Transport (HEBT) line of the PIP-II Injector Test (PIP2IT)

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**Document Approval**

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# Introduction

PIP-II is an 800-MeV H- SRF linac that will work in a beam pulse mode (0.55 ms, 20 Hz), but CW RF, for injection into the Booster [1].

The PIP-II Injector Test (PIP2IT) is an integrated system test for the PIP-II front end [2]. It is part of the broader program of research and development aimed at key components of PIP-II. The successful completion of this test will validate the concept for the PIP-II front end and demonstrate the viability of novel front end technologies (e.g. MEBT chopping system) that will find applications beyond PIP-II in the longer term.

# PIP2IT beam line components

PIP2IT is located in the existing Cryomodule Test Facility (CMTF) and utilizes the existing infrastructure. The PIP2IT accelerator includes the following seven subsystems shown in Figure 1:

**Ion**

**Source**

**LEBT**

**RFQ**

**MEBT**

**HWR**

**SSR1**

**HEBT**

**Figure 1:** Major subsystems in the PIP2IT linac.

* A DC H- ion source capable of delivering up to 15 mA (5 mA nominal) at 30 keV [3].
* A Low Energy Beam Transport (LEBT) section with beam pre-chopping [4].
* A CW Radio Frequency Quadrupole (RFQ) operating at 162.5 MHz and capable of delivering up to 10 mA at 2.1 MeV [5].
* A Medium Energy Beam Transport (MEBT) section with integrated wideband beam chopper and 21 kW beam absorber capable of generating a bunch pattern consistent with bucket-to-bucket injection into the Booster [6].
* Two low-beta superconducting cryomodules (HWR and SSR1) capable of accelerating up to 2 mA (averaged over 1s) of beam to 20-25 MeV [7, 8].
* A High Energy Beam Transport (HEBT) section [9], which consists of a beam diagnostic section and a dump capable of accommodating a maximum beam power of 700 W with energies of up to 25 MeV for extended periods.

# Scope

This document defines the set of measurements to be carried out at PIP2IT in the configuration described in the previous section. It does not presume the use of specific diagnostics or details of the beam line optics. Nevertheless, the fact that some instrumentation already exists (e.g. used in the MEBT) has been considered.

# Acronyms

|  |  |
| --- | --- |
| CMTF | Cryomodule Test Facility |
| CW | Continuous Wave |
| DC | Direct Current |
| HEBT | High Energy Beam Transport |
| HWR | Half-Wave Resonator |
| L2 | WBS Level 2 |
| L3 | WBS Level 3 |
| LEBT | Low Energy Beam Transport |
| MEBT | Medium Energy Beam Transport |
| PIP-II | Proton Improvement Plan II Project |
| PIP2IT | PIP-II Injector Test |
| RF | Radio Frequency |
| RFQ | Radio Frequency Quadrupole |
| SSR1 | Single Spoke Resonator type I |
| SRF | Superconducting Radio Frequency |
| TC | Teamcenter |
| WFE | Warm Front End |

# Reference

|  |  |  |
| --- | --- | --- |
| **#** | **Reference** | **Document #** |
| 1 | PIP-II Functional Requirements Specification | ED0001222 |
| 2 | [PXIE White Paper](http://projectx-docdb.fnal.gov/cgi-bin/ShowDocument?docid=966) | - |
| 3 | PXIE Ion Source Functional Requirements Specification | ED0001288 |
| 4 | PXIE LEBT Functional Requirements Specification | ED0001289 |
| 5 | PXIE RFQ Functional Requirements Specification | ED0001300 |
| 6 | PXIE MEBT Functional Requirements Specification | ED0001303 |
| 7 | PIP-II HWR Cryomodule Functional Requirements Specification | ED0001313 |
| 8 | PIP-II SSR1 Cryomodule Functional Requirements Specification | ED0001316 |
| 9 | PIP2IT HEBT Technical Requirements Specification | ED0008220 |
| 10 | PIP2IT Shielding Assessment | - |

# Assumptions

* The HEBT beam line has a straight-line configuration.
* The beam dump is the existing “SNS” beam dump with some modifications for radiation shielding purposes.
* There is no element for longitudinal focusing in the HEBT.
* Short beam macro-pulses (5 - 20 s) may be used for measurements with intercepting devices.

# Minimum set of measurements

The nominal minimum beam parameters to achieve concurrently are:

* 2 mA averaged over 1 s
  + This corresponds to 30 pC per bunch with a bunch pattern consistent with bucket-to-bucket injection into the Booster
* Macro-pulse length: 0.55 ms
* 20 Hz repetition rate for the macro pulse
* 22 MeV

Table 1 lists the parameters that need to be measured to properly characterize the beam that exits the two cryomodules. It also indicates expectations for nominal values and the level of accuracy which the measurements must satisfy.

**Table 1:** Baseline measurements

|  |  |  |
| --- | --- | --- |
| Beam parameter | Nominal value | Accuracy of the measurement |
| Beam energy | 22 MeV | ±2 % |
| Current (averaged over 1 s)\* | 2 mA | ±1.5 % |
| Transmission through both cryomodules | 98% | ±2 % |
| Beam position (averaged over the macro-pulse) | N/A | ±10 m (relative) |
| Transverse emittance (rms, normalized) | 0.25 m | ±10 % |
| Longitudinal emittance (rms, normalized) | 0.4 m | ±20 % |
| Bunch extinction | < 5×10-3 | ±10-3 |
| Transverse phase space distributions | N/A | 0.1% (relative)† |

\* The beam current should be measured at the exit of the SSR1 cryomodule (to measure beam transmission) and at the end of the beam line (i.e. the beam dump).

† Relative phase space density at the tails of the distribution

In addition to the parameters listed in Table 1, the HEBT shall include the instrumentation necessary to view and measure the train structure of the beam (i.e. bunch selection pattern formed with the MEBT chopping system).

Also, the macro-pulse length shall not exceed 1 ms and the averaged current (over 1 s) shall not exceed 3 mA. In addition, the current averaged over 1 s shall not exceed 30 A.

# Additional comments

The nominal values for the beam parameters listed in Table 1 (and their associated measurement accuracy) are for a beam energy of 22 MeV and a beam current of 2 mA, concurrently. However, measurements may be carried out for a wider range of energies, for which the beam parameters’ ‘nominal’ values may differ from those in Table 1. In particular, beam measurements at energies higher than 22 MeV may require decreasing the averaged beam current to satisfy the operational limitations stated in the Radiation Shielding Assessment [10].

Also, the bunch length, which is of the order of 20 ps (nominal) at the exit of the SSR1 cryomodule, will grow as it propagates down the HEBT line where longitudinal focusing is absent. To better measure the longitudinal emittance and lessen the burden of the design for the measuring device (e.g. Fast Faraday Cup), a longer bunch length is in fact desirable. Therefore, the drift distance from the SSR1 to the measuring device may be tailored to allow measuring the beam emittance with the accuracy stated in Table 1.