Fermi National Accelerator Laboratory

Fermilab

PIP-II Medium Energy Beam Transport (MEBT) Technical Requirements Specification

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Document Approval

Signatures Required	
Originators: Lionel Prost, WFE L3 Manager Alexander Shemyakin, Senior Scientist	Checker in Teamcenter
Reviewer: Lidija Kokoska, Project Engineer	Checker in Teamcenter
Approver: Jerry Leibfritz, Linac Installation & Commissioning L2 Manager	Approver in Teamcenter
Stakeholder Reviews performed off-line using TRS Metadata sheets	Dataset in Teamcenter
Reviewer: Arden Warner, MPS L3 Manager	*Approval in TRS metadata sheet*
Reviewer: Brian Chase, LLRF L3 Manager	*Approval in TRS metadata sheet*
Reviewer: Vic Scarpine, Instrumentation L3 Manager	*Approval in TRS metadata sheet*
Reviewer: Raul Campos, Vacuum L3 Manager	*Approval in TRS metadata sheet*
Reviewer: Bruce Hanna, Magnets/PS L3 Manager	*Approval in TRS metadata sheet*
Reviewer: Jim Steimel, HPRF, RF Distribution L3 Manager	*Approval in TRS metadata sheet*
Reviewer: Maurice Ball, Building Infrastructure L3 Manager	*Approval in TRS metadata sheet*
Reviewer: Randy Zifko, Safety Systems L3 Manager	*Approval in TRS metadata sheet*
Reviewer: Jim Patrick, Controls L3 Manager	*Approval in TRS metadata sheet*
Reviewer: Joe Ozelis, Half-wave Cryomodule L3 Manager	*Approval in TRS metadata sheet*
Reviewer: Curt Baffes, Linac Installation L3 Manager	*Approval in TRS metadata sheet*
Reviewer: Eduard Pozdeyev, Project Scientist	*Approval in TRS metadata sheet*

Revision History

Revision	Date of Release	Description of Change
---	--	Initial Release for Review. An old version of the MEBT FRS was containing some of the information now appearing in this TRS.

Table of Contents

1. SCOPE

This TRS describes technical requirements for the MEBT, which is defined as a set of elements between the vacuum valves at the exit of the RFQ and entrance of the HWR. The TRS details the functional requirements specified in the PIP-II MEBT FRS [6].

2. ACRONYMS, TERMS, AND DEFINITIONS

ACCT	AC Current Transformer (Toroid)
BM	Beam Mode
BPM	Beam Position Monitor
CAM	Control Account Manager
DCCT	DC Current Transformer
DPI	Differential Pumping Insert
FESHM	Fermilab ES&H Manual
FFC	Fast Faraday Cup
FRCM	Fermilab Radiological Control Manual
FRS	Functional Requirements Specification
HBB	High-Bay Building
HEBT	High Energy Beam Transport
HPRF	High Power RF
HWR	Half-Wave Resonator cryomodule
ID	Inner Diameter
ISD	Interface Specification Document
L2	WBS Level 2
L2M	WBS Level 2 Manager
L3	WBS Level 3
L3M	WBS Level 3 Manager
LCW	Low Conductivity Water
LEBT	Low Energy Beam Transport
LLRF	Low Level RF
MEBT	Medium Energy Beam Transport
MPS	Machine Protection System
ORC	Operation Readiness Clearance
PIP-II	Proton Improvement Plan II Project

PRD	Physics Requirements Document
RDS	Room Data Sheet
RF	Radio Frequency
RFQ	Radio-Frequency Quadrupole
RMS	Root Mean Squared
RPU	Ring Pick-Up
SRF	Superconducting Radio-Frequency
TC	Teamcenter
TRS	Technical Requirements Specification
TSW	Technical Scope of Work
UHV	Ultra-High Vacuum
WBS	Work Breakdown Structure
WFE	Warm Front End

3. REFERENCED DOCUMENTS

#	Reference	Document #
1	PIP-II MEBT EPDM	ED0001228
2	Fermilab Engineering Manual	NA
3	Fermilab Environmental Safety and Health Manual	NA
4	Fermilab Radiological Control Manual	NA
5	PIP-II Parameters PRD	ED0010216
6	PIP-II Accelerator Commissioning and Start-Up Plan	PIP-II-doc-5420
7	PIP-II MEBT FRS	ED0001303
8	MEBT and HEBT quadrupoles and dipole correctors TRS	ED0003467
9	Bunching cavity FRS	ED0001307
10	PIP-II MEBT Kicker Assembly TRS	ED0008094
11	PIP-II FDR MEBT kicker review	ED0007959
12	Performance of the MEBT chopper in 2021 run	PIP-II-doc-5375
13	MEBT Vacuum system FRS	ED0001308
14	DPI FRS	ED0004472
15	MEBT scraper FRS	ED0001306
16	Diagnostics FRS	ED0008303
17	MPS TRS	ED0013140

18	Beam Instrumentation PRD	ED0010230
19	Beam Position Monitor TRS	TBD
20	WFE/Controls ISD	TBD
21	WFE/LLRF ISD	TBD
22	WFE/HPRF ISD	TBD
23	WFE/MPS ISD	TBD
24	WFE/BI ISD	TBD
25	WFE/Vacuum ISD	TBD
26	WFE/BldgI ISD	TBD
27	PIP-II Misalignment Tolerances PRD	ED0010231
28	Room Data Sheet	ED0009544

4. ROLES AND RESPONSIBILITIES

4.1. Originator

Responsible for TRS preparation, including layout, proper format, requirement identification, requirement verification expectations, requirement traceability, and additional descriptive detail, as appropriate. The originator is expected to engage subject matter experts as needed to ensure technical content is appropriately assessed and captured.

4.2. Reviewer

Responsible for review of the TRS content, ensuring accuracy and completeness of all requirements and supplemental descriptive detail, as applicable.

4.3. Approver

The L2 Manager will evaluate the basis for requirements definition, ensure that requirements are properly articulated, and ensure that they align with higher level requirements specifications, as applicable. The L2M will ensure that CAMs, associated engineering staff, and other Systems Managers are properly engaged and notified of the document's technical implications. Only the System Manager responsible for the work product addressed in the specification is expected to provide approval.

5. REQUIREMENTS

5.1. System Definition

5.1.1. Background

The MEBT is defined as the beam line encompassing all the elements between the vacuum valves at the exit of the RFQ and entrance of the HWR. It comprises a vacuum system, quadrupole magnets, dipole corrector magnets, bunching cavities, movable scrapers, kickers, an absorber, and various beam diagnostics.

5.1.2. High Level Operations Concepts/Scenarios

The MEBT manipulates the beam coming out of the RFQ, preparing its bunch structure and bunch parameters for injection into the SRF linac. The input beam pulse length and current are defined by the ion source and the LEBT chopper, and bunches are coming in 162.5 MHz trains created by the RFQ. The nominal repetition rate for those trains is 20 Hz, and the nominal pulse length is 0.55 ms. The other nominal parameters of the beam coming to the MEBT from the RFQ are specified in the PIP-II Parameters PRD [5] and shown for convenience in Table 5.1.

Table 5-1: Parameters of the beam coming out of the RFQ for nominal mode of operation

Current, mA	Beam Energy (MeV)	Emittance, H/V, norm (μm)		Emittance, Long., norm, (μm)		Beam Size, H/V,Trans.,typ., (mm)	Bunch length, (deg) @ *162.5 MHz*	Energy spread, (%)
		rms	99.99%	rms	99.99%	rms	rms	rms
5	2.1	0.21/0.21	3.87/4.0	0.34	6.0	1/0.5	7.1	0.4

When it is considered rational, the MEBT components may be designed to perform adequately for parameters exceeding those nominals in order to accommodate future upgrades of PIP-II to higher duty factors. In addition, the MEBT and its sub-systems should be designed such as to be capable of accommodating an input peak beam current of 10 mA.

Parameters in the tables from Section 5.2 are specified for **2 mA beam pulses with at least 10 μs pulse length**, which covers all the Beam Modes defined in the PIP-II Accelerator Commissioning and Start-Up Plan [6].

The final bunch structure is created by the MEBT chopping system. The requested bunch structure can be aperiodic and almost arbitrary only limited by the maximum average (over 50 ms) switching frequency that the kicker driver electronics can reliably provide.

The MEBT diagnostics allow to characterize rms beam properties in all planes and beam distribution in the transverse planes.

The beam transverse tails are managed by a scraping system that consists of 4 identical scraping stations with 4 scraper plates in each.

In the nominal operation scenario, the MEBT has common vacuum with the HWR. To preserve the quality of HWR SRF cavities, the downstream portion of the MEBT is particle-free and UHV.

To protect the MEBT elements from beam-induced damage, some of the MEBT components communicate information about their state to the MPS, which in turn leads to a set of beam permits determining the operational status of the WFE.

The ion source is serviceable while the SRF linac is running nominally. Also, the WFE is expected to be viewable from an observation deck by the general public. To shield radiation from the SRF linac, a concrete wall separates the High-Bay Building (HBB) area where the WFE resides from the tunnel. Accordingly, while most of the MEBT line is located in the HBB, a small section penetrates the tunnel through that concrete wall.

In the context of this TRS, the Linac's modes of operation with beam are defined as "Operational", "Long Pulse" (low duty), and "Diagnostic" (low –and high-frequency) modes, corresponding to modes BM4, BM3, and BM1/BM2, respectively, as defined in Ref. [6]. For commissioning, the MEBT uses the Diagnostic mode. In this mode, the LEBT chopper creates short pulses with a duration of 10 µs. The beam current may be reduced to 1 mA either in the ion source/LEBT or by scraping with the upstream sets of scrapers in the MEBT.

In the Operational and Long Pulse modes, the beam current coming out of the MEBT averaged over the pulse is limited to 2 mA with most of the excessive charge removed by the MEBT chopping system. The charge of bunches coming out of the MEBT may be adjusted by regulating the current from the RFQ, by transverse scraping with the upstream set of scrapers, or by transverse scraping at the MEBT absorber edge.

Initial commissioning of the MEBT is carried out in a shorter configuration where the beam is physically prevented from going into the SRF linac.

5.1.3. System Diagram

For referring purposes, the MEBT is presented as a set of sections, with each section extending from the upstream flange of a quadrupole assembly (either doublet or triplet) to the flange mating the next downstream quadrupole assembly. The last section ends at the vacuum valve of the HWR. The MEBT diagram where each section is represented by a box is shown in Figure 5-1.

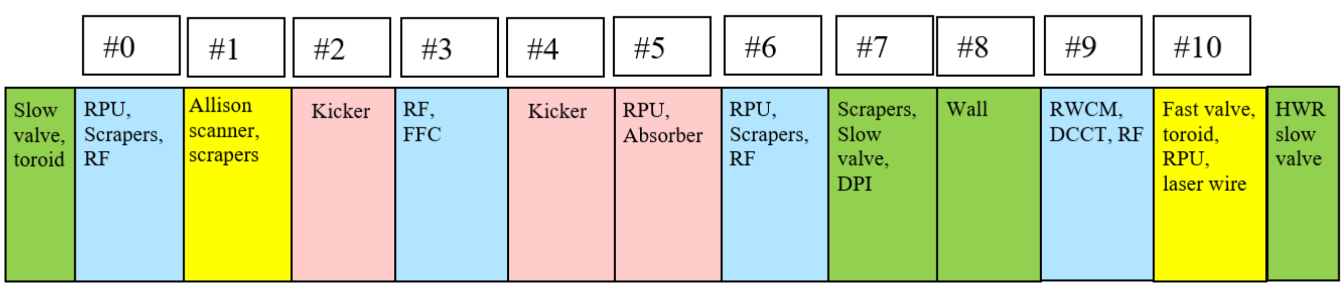

Figure 5-1: Diagram of the PIP-II MEBT.

The borders between sections correspond to a doublet or a triplet, and the main components are listed inside the boxes. Color coding reflects the main function of the section as follows:

- Blue are the sections containing the bunching cavities (marked as "RF").
- Red are the sections with the chopping system components.
- Yellow are the sections dedicated to beam instrumentation.
- Green are the remaining sections that cannot be categorized as blue, red, or yellow.

The two green boxes on both ends contain components belonging, in this nomenclature, to the RFQ (upstream) and the HWR (downstream).

5.1.4. Interface Definition

The MEBT interfaces with the following systems:

- HPRF
- LLRF
- Vacuum
- Water
- Controls
- Beam instrumentation
- MPS

These interfaces are described in detail in ISDs [20-26] at the subsystem level (e.g. interface between HPRF and bunching cavities).

5.1.4.1. HPRF interface

The MEBT contains 4 bunching cavities, which are powered from 4 independent RF power amplifiers. RF power is distributed to the bunching cavities via coaxial cables connected to power couplers at the cavities.

5.1.4.2. LLRF interface

The RF parameters of the bunching cavities are regulated by the Low-Level RF system, including resonance control and beam loading compensation. LLRF also implements and manages RF interlocks. In addition, LLRF provides the bunch sequence and beam-synchronized timing triggers to the kicker system via the Beam Pattern Generator.

5.1.4.3. Vacuum interface

Several turbomolecular and ion pumps are used along the beam line to achieve the vacuum requirements **T-ED0014432-F001** and **T-ED0014432-F002** in Table 5-7. Vacuum valves are used to isolate the MEBT from the RFQ and the HWR, as well as Sections 0-6 from Section 7-10. A Fast-Acting Valve protect the HWR from vacuum incidents in the MEBT.

5.1.4.4. Water interface

Several components in the MEBT require cooling by cleaned, non-corrosive, filtered water. Those components are: 2 kickers, MEBT absorber, 4 bunching cavities, 4 scraper/wire scanners assemblies, and 2 Allison scanners.

5.1.4.5. Controls interface

Adequate controls are required to operate and monitor the MEBT and its sub-systems. In particular, the following components require motion control: 16 scrapers, 4 wire scanners, 4 bunching cavity tuners, 2 Allison scanners, and FFC.

5.1.4.6. Beam instrumentation interface

Several beam diagnostics shall be located in the MEBT in order to properly characterize the beam and tune the beam line. A list of diagnostics is specified in Refs. [16] and [18], and their placement in the MEBT is described in Table 5-9.

5.1.4.7. Machine Protection System interface

Several MEBT components provide signals to the MPS to protect both those components and the beam line components downstream. These signals are listed in Table 5-10.

5.2. Requirements

5.2.1. Performance

The nominal parameters of the beam coming out of the MEBT are specified in the PIP-II Parameters PRD [5] and are partially copied in Table 5-2.

Table 5-2: Parameters of the beam coming out of the MEBT for nominal mode of operation

Requirement #	Requirement	Value	Unit
T-ED0014432-A001	Beam energy	2.1	MeV
T-ED0014432-A002	Beam current averaged over any 1 µs during the beam pulse	2	mA
T-ED0014432-A003	Transverse emittance, H/V, rms, normalized	0.21/0.2	µm
T-ED0014432-A004	Longitudinal emittance, normalized	0.35	µm
T-ED0014432-A005	The bunch pattern shall be optimized for injection into the Booster	-	-
T-ED0014432-A006	Extinction (calculated as the ratio of the average charge in the cleaned buckets to the average charge of passed bunches)	0.1%	-

As mentioned previously, the pulse length is either 10 μs or 550 μs depending on the Beam Mode, and the pulses' repetition rate may vary between 1 Hz and 20 Hz.

5.2.2. Physical Characteristics

Table 5-3: General requirements

Requirement #	Requirement Statement
T-ED0014432-B001	The MEBT shall consist of the following sub-systems: 1. Transverse focusing and steering 2. Longitudinal focusing 3. Chopping 4. Vacuum 5. Scraping 6. Diagnostics
T-ED0014432-B002	The MEBT shall consists of 11 sections as outlined in Fig. 5-1. Each section begins either with a quadrupole doublet or triplet.
T-ED0014432-B003	Section #8 shall include a radiation shielding wall. The design of the wall shall allow maintenance work on the ion source or LEBT while the SRF linac runs at nominal parameters.

T-ED0014432-B004	Ionizing radiation produced by the MEBT shall be compatible with visits of the general public to the high bay building balcony under the guidelines of the FRCM.
T-ED0014432-B005	The minimum beam tube aperture (ID) shall be 30 mm. The kickers, the position of the absorber edge with respect to the beam tube downstream, the DPI, and the scrapers when in the inserted positions shall be excluded from this requirement.
T-ED0014432-B006	The MEBT shall be configurable for operating independently sections 0-6 while preventing the beam from entering the HWR.
T-ED0014432-B007	The MEBT shall be configurable for commissioning independently Sections 0-6 while allowing personnel access to the linac tunnel. This shall be accomplished with the implementation of an air gap in Section 6, just downstream of the 3rd scraping station.
T-ED0014432-B008	Elements in the MEBT shall be protected from beam-induced damage. To this end, a subset of the MEBT components shall provide appropriate signals to the MPS as detailed in Table 5-10.
T-ED0014432-B009	All major MEBT components shall provide capability of alignment to tolerances specified in [27].
T-ED0014432-B010	Placement of cables and water hoses should not interfere with alignment.

The sub-systems listed in [T-ED0014432-B001] are specified further in the tables below. Overall space, power and cooling requirements are captured in the RDS [28].

Table 5-4 presents a general description of the transverse focusing and steering subsystems. Parameters of all magnets as well as their positions within doublets and triplets are specified in Ref. [8] and partially copied to Table 5-4 for completeness.

Table 5-4: Transverse focusing and steering

Requirement #	Requirement	Value	Unit
T-ED0014432-C001	Transverse focusing shall consist of 2 quadrupole doublets and 9 quadrupole triplets.	-	-
T-ED0014432-C002	Each doublet shall consist of two long ("QF") quadrupoles.	-	-
T-ED0014432-C003	Each triplet shall have a QD-QF-QD structure, where "QD" designates a short quadrupole.	-	-
T- ED0014432-C004	Each doublet and triplet shall be followed by a pair of dipole correctors, capable of steering the beam in the horizontal and vertical planes.	-	-
T-ED0014432-C005	All MEBT magnets shall be air-cooled.	-	-
T-ED0014432-C006	Maximum integrated gradient for QF will be	1.5	T
T-ED0014432-C007	Maximum integrated gradient for QD will be	0.85	T

T-ED0014432-C008	Maximum field integral for dipole corrector (*each plane, at nominal position near a quadrupole*)	2.1	mT·m
T-ED0014432-C009	Distance between doublets (*measured between the centers of the upstream quadrupoles in successive doublets*).	900	mm
T-ED0014432-C010	Distance between the centers of the upstream quadrupole in the second doublet and the QF quadrupole in the first triplet	1225	mm
T-ED0014432-C011	Distance between centers of QF quadrupoles in neighboring triplets	1175	mm

Table 5-5 presents a general description of the longitudinal focusing subsystem. Parameters of bunching cavities are specified in Ref. [9] and partially copied to Table 5-5 for completeness.

Table 5-5: Longitudinal focusing

Requirement #	Requirement	Value	Unit
T-ED0014432-D001	MEBT longitudinal focusing shall consist of 4 identical normally conducting bunching cavities	-	-
T-ED0014432-D002	Bunching cavity frequency	162.5	MHz
T-ED0014432-D003	Maximum energy gain per bunching cavity	100	keV
T-ED0014432-D004	Bunching cavities will be located in MEBT sections	0, 3, 6, 9	
T-ED0014432-D005	Bunching cavities will be water-cooled		

The bunch pattern is created by the MEBT chopping system by directing unnecessary bunches to the absorber. Table 5-6 presents a general description of the chopping subsystem. Parameters of the chopping system are specified in Ref. [10] and partially copied to Table 5-6 for completeness.

Extinction (requirement **T-ED0014432-A007**) depends on multiple operationally set MEBT parameters that define the transverse beam size, bunch length, trajectory with the kickers off, and amount of beam scraping, as well as on the tuning of the ion source, LEBT, and RFQ. Based on simulations and PIP2IT experience ([11], [12]), the requirement **T-ED0014432-A007** is translated into the requirement **T-ED0014432-E005** for the kicker deflection.

Table 5-6: Chopping system

Requirement #	Requirement	Value	Unit
T-ED0014432-E001	The chopping system, forming the bunch pattern in the MEBT, shall consist of two kickers and one absorber	-	-
T-ED0014432-E002	The chopping system shall be capable of forming any bunch patterns satisfying the conditions in Table 5-2.	-	-

T-ED0014432-E003	The chopping system components shall be located in sections 2, 4 (kickers), and 5 (absorber)	-	-
T-ED0014432-E004	Average (over the beam pulse) deflection of bunches designated for acceleration in the SRF linac (by each kicker, for any pattern)	< +0.6	mrad
T-ED0014432-E005	RMS scatter of deflection of bunches designated for acceleration in the SRF linac (by each kicker, for any pattern)	< 0.37	mrad
T-ED0014432-E006	Deflection of bunches designated for removal to the absorber (by each kicker)	7.4±10%	mrad
T-ED0014432-E007	The kicker in section 2 shall deflect the beam down	-	-
T-ED0014432-E008	The kicker in section 4 shall deflect the beam up	-	-
T-ED0014432-E009	Minimum aperture in the kickers, vertical/horizontal	13/20	mm
T-ED0014432-E010	Kicker protection electrodes shall be biased up to	+100	V
T-ED0014432-E011	The absorber shall be capable of sustaining an average beam power of [(nominal) / (recommended for future upgrades)]	0.12 / 21	kW
T-ED0014432-E012	Nominal gap between the MEBT vacuum pipe axis and the downstream edge of the absorber's beam-accepting surface	4	mm
T-ED0014432-E013	Vertical adjustment range of the absorber's beam-accepting surface w.r.t. the beam line centerline	+9 / -1	mm

The MEBT vacuum system extends from the downstream RFQ vacuum valve to the upstream HWR valve. Parameters of the vacuum system are specified in Ref. [13] and partially copied to Table 5-7 for completeness. The values are specified for the beam parameters listed in Table 5-1 and Table 5-2.

Table 5-7: Vacuum system

Requirement #	Requirement	Value	Unit
T-ED0014432-F001	Pressure upstream of section #7 shall not exceed	$5 \cdot 10^{-7}$	Torr
T-ED0014432-F002	Pressure at the downstream end of the MEBT shall not exceed	$1 \cdot 10^{-9}$	Torr
T-ED0014432-F003	Section #7 shall contain the Differential Pumping Insert (DPI) [14]	-	-
T-ED0014432-F004	DPI vacuum pipe dimensions, ID/length	10/200	mm
T-ED0014432-F005	The DPI shall be biased up to	+100	V
T-ED0014432-F006	Sections 8, 9 and 10 shall be designed, manufactured, and assembled according to low-particulate standards	-	-
T-ED0014432-F007	Section 7 shall contain a vacuum valve to fulfil **T-ED0014432-B006** and to assist with maintenance.	-	-

T-ED0014432-F008	Section 10 shall contain a fast-acting vacuum valve to protect the HWR in case of a vacuum accident in the MEBT	-	-

The MEBT scraping system manages the beam transverse tails, protects sensitive elements from beam irradiation, forms a pencil beam for commissioning, and allows measuring the beam rms size by intercepting the beam. The scraping system consists of a set of 16 movable plates (individual scrapers). Scraper parameters are specified in Ref. [15] and partially copied to Table 5-8 for completeness. In the table, a vacuum assembly outfitted with scrapers is referred to as a scraper station.

Table 5-8: Scraping system

Requirement #	Requirement	Value	Unit
T-ED0014432-G001	Scrapers shall be mounted in 4 stations located in ***Sections***	0, 1, 6, 7	-
T-ED0014432-G002	Each station shall contain 4 scraper plates arranged as shown in Figure 5-2 (i.e. top, bottom, left, right).	-	-
T-ED0014432-G003	Each scraper plate shall be radiation-cooled, independently movable, and electrically isolated	-	-
T-ED0014432-G004	A fully retracted plate shall be outside of the 30 mm beam aperture	-	-
T-ED0014432-G005	A fully inserted plate shall completely overlap the 30 mm beam aperture	-	-
T-ED0014432-G006	All 4 scrapers in each station can be inserted at the same time without interference	-	-
T-ED0014432-G007	While intercepting the beam tails, any individually inserted scraper shall withstand the average power of	75	W
T-ED0014432-G008	Maximum total average power intercepted by 4 scrapers in the same station	200	W
T-ED0014432-G009	The scraper plate shall withstand intercepting completely a 10-mA beam with a pulse length of up to	10	µs
T-ED0014432-G010	The scraper plates shall be biased up to	+100	V
T-ED0014432-G011	The flange-to-flange length of each scraper station shall not exceed (longitudinal direction)	180	mm
T-ED0014432-G012	The scraper station’s vacuum chamber shall incorporate two diagonal ports for Wire scanners or other diagnostics	-	-

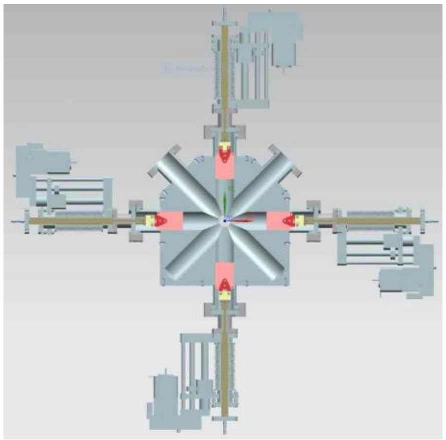

Figure 5-2: Model of a scraper station.

The MEBT diagnostics include tools to measure the beam transverse positions and density distribution; the beam current; bunch phase and longitudinal distribution. Also, while all electrically isolated electrodes in the MEBT supply current readings to the MPS (Table 5-10), their signals need to be duplicated for tuning purposes. Diagnostics are specified in Ref. [16] and [18]. Table 5-9 summarizes their locations and some key functions for completeness.

Table 5-9: MEBT diagnostics.

Requirement #	Requirement	Value	Unit
BPMs			
T-ED0014432-H001	Each doublet or triplet shall include one BPM attached to the central quadrupole in triplets or the upstream quadrupole in doublet, for a total of 11 BPMs	-	-
T-ED0014432-H002	A wideband BPM system will be capable of measuring the positions of individual bunches*	-	-
T-ED0014432-H003	BPMs with the wideband system (electronics) shall be those located between sections #2 and #5 (i.e. 3 BPMs)	-	-
Beam Current Monitors			
T-ED0014432-H004	An ACCT shall be placed at the entrance of the MEBT	-	-
T-ED0014432-H005	An ACCT shall be placed in ***Section 10***	-	-
T-ED0014432-H006	ACCT beam current measuring range for pulses ≥ 10 μs shall be	1 - 10	mA
T-ED0014432-H007	A DCCT shall be placed in ***Section 9***	-	-
Additional diagnostics			
T-ED0014432-H008	Four (4) Wire Scanners shall be located in the same vacuum cans as the MEBT scrapers in ***Sections***	0, 1, 6, 7	-

T-ED0014432-H009	Each Wire scanner shall provide the transverse beam distribution in both X and Y planes	-	-
T-ED0014432-H010	Wire Scanners should have the capability of being biased up to (absolute value)	100	V
T-ED0014432-H011	Two Allison emittance scanners (X/Y) shall be placed in ***Section 1***	-	-
T-ED0014432-H012	A Fast Faraday Cup shall be placed in ***Section 3***	-	-
T-ED0014432-H013	A Resistive Wall Current Monitor shall be placed in ***Section 9***	-	-
T-ED0014432-H014	A Laser Wire shall be placed in ***Section 10***	-	-
T-ED0014432-H015	Diagnostics should provide readings of the absorber current	-	-
T-ED0014432-H016	Diagnostics should provide imaging of the absorber surface intercepting beam.	-	-
Complementary readouts			
T-ED0014432-H017	In addition to the signals delivered to the MPS, current readings from electrically isolated electrodes should be available; the signals origins and number of channels are specified in **T-ED0014432-H018** thru **T-ED0014432-H020**	-	-
T-ED0014432-H018	Number of channels for the scraper plates	16	-
T-ED0014432-H019	Number of channels for the kicker protection electrodes	4	-
T-ED0014432-H020	Number of channels for the DPI aperture-restricting pipe	1	-

* The wideband BPM system does measure the beam phase or 1st harmonic intensity [16].

The MPS protects the MEBT components from beam-induced damage and is described in Ref. [17]. The MEBT signals that shall be provided to the MPS are specified in Table 5-10.

Table 5-10: Signals to MPS

Requirement #	Requirement	Value	Unit
T-ED0014432-I001	The MEBT shall have 4 RPUs, providing the MPS with signals proportional to the beam current. The RPUs shall be located in ***Sections***	0, 5, 6, 10	-
T-ED0014432-I002	Each of the 16 scraper plates shall provide reading of its current to the MPS	-	-
T-ED0014432-I003	The DPI aperture-restricting pipe shall provide readings of its current to MPS	-	-
T-ED0014432-I004	Each of the 4 kicker protection electrodes shall provide readings of its current to the MPS	-	-

T-ED0014432-I005	The absorber shall provide readings of its current to the MPS	-	-
T-ED0014432-I006	The MEBT vacuum system shall provide its status information to the MPS	-	-
T-ED0014432-I007	Each of the 2 kickers shall provide its status information to the MPS	-	-
T-ED0014432-I008	Each of the 2 Allison scanners shall provide to the MPS information on whether they are fully retracted	-	-
T-ED0014432-I009	The Fast Faraday Cup shall provide to the MPS information on whether it is fully retracted	-	-
T-ED0014432-I010	Each of the 16 scraper assemblies shall provide to the MPS information on whether they are fully retracted.	-	-
T-ED0014432-I011	Two (2) scraper assemblies shall ***directly*** provide to the MPS information on whether they are fully inserted. The scraper assemblies shall be located in **Section**	6	-
T-ED0014432-I012	The scrapers from Section 6 instrumented for the MPS shall be the "**Left**" and "**Right**" assemblies.	-	-
T-ED0014432-I013	Each of the 4 wire scanners shall provide to the MPS information on whether it is fully retracted	-	-

5.2.3. Reliability, Maintainability, and Availability

The MEBT is composed of multiple subsystems and components thus a multitude of failure points. Most of those are detailed as appropriate when defining and specifying those elements. However, components installed in the MEBT line shall be designed for continuous operation without needs for particular maintenance over the lifetime of the PIP-II facility, except for the vacuum system; preventive maintenance shall be conducted on the vacuum pumping stations as appropriate. Note that building infrastructure (e.g. water cooling systems) maintenance and availability are covered elsewhere.

The MEBT will be mostly located within the HBB, with only a small portion of the beam line in the tunnel proper downstream. A shielding wall shall ensure that all components residing in the HBB remain free from any activation such that hands-on maintenance can take place as soon as the beam is inhibited. Experience at PIP2IT demonstrated that the 2.1 MeV beam in itself will not activate MEBT components. SRF Linac tunnel rules and protocols shall be adopted to access the portion of the MEBT in the tunnel, which may be activated, depending on the running conditions, and running time. Moreover, electronics equipment in that part of the MEBT may experience higher failure rates than upstream due to irradiation.

5.2.4. Transportability

The MEBT components shall be assembled on a set of independent stands (a.k.a. girders). The girders shall be designed such that they can be individually transported without removing the components they carry. Accordingly, the beam pipe should be such that it can be interrupted at locations consistent with the end/beginning of said girders.

5.2.5. Software

The MEBT shall be controlled and operated by software either common to the entire PIP-II complex or developed for diagnostics specific to the MEBT.

5.2.6. Safety

There are multiple hazards associated with the MEBT and its components. Most of the safety requirements will be addressed at the subsystem or component level and are beyond the scope of this document. In addition, the MEBT as a whole is subject to the normal lab-wide regulations for accelerators and accelerator enclosures and will be subject to Accelerator Readiness Reviews (ARR) and Operational Readiness Clearances (ORC) as appropriate.

While the MEBT will be located in the High-Bay Building, in a pit with an open roof for public viewing during regular operation, its access at the floor level will be restricted. The MEBT shall be located in an interlocked area and most accesses under normal conditions are expected to fall under controlled access policies and regulations.

5.3. Design and Construction Standards

Design and construction standards are covered at the sub-system level.

5.4. Documentation

Documentation requirements will be addressed at the subsystem or component level as appropriate. Installation travelers will be written and managed within the Vector system. ORCs are requested, conducted, granted, and archived via the TSW ORC Tool (website).

5.5. Technical Requirements Summary Table

All the requirements listed within this document are compiled into an Excel spreadsheet added as a data set within TC item ED0014432.

6. VERIFICATION

Verification plans for each subsystem or component will ensure readiness for ARRs and ORCs. At the beamline level, beam commissioning and achieving “Booster Injection” beam parameters shall constitute the verification step.

7. QUALITY ASSURANCE PROVISIONS

Quality control will be addressed at the subsystem or component level as appropriate. At the beamline level, results from beam commissioning will assess whether the MEBT conforms to the specifications or not.

APPENDIX A – *(NOTES, BACKGROUND, DIAGRAMS, CALCULATIONS, ETC.)*