Functional Requirement Specification

PXIE MEBT Beam Position Monitors

Prepared by: A. Shemyakin, V, Scarpine, B. Chase	Fermilab AD	shemyakin@fnal.gov #4440
Approved by: V. Lebedev, CW Linac Scientist	Fermilab AD	#2258
Approved by: R. Stanek, PXIE Lead Engineer	Fermilab Directorate	#3519
Acknowledge by: M. Alvarez, BPM mechanical designer	Fermilab AD	# 8746
Acknowledge by: N. Eddy, Instrumentation Department Head	Fermilab AD	# 6860

Revision History

Revision	Date	Section No.	Revision Description
0	03/08/2013	All	Initial release.

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1 Introduction:

The main diagnostics for measuring of transverse positions and bunch phases in the PXIE Medium Energy Beam Transport (MEBT) [1] is a set of Beam Position Monitors (BPMs). This specification describes functional requirements for the MEBT BPMs.

2 Scope:

The PXIE MEBT beam optics scheme [2] assumes transverse focusing by 2 quadrupole doublets and 7 triplets. A BPM assembly is installed between the quadrupoles of each doublet and triplet. Each assembly is capable of providing information about the horizontal and vertical (X and Y) beam position, bunch phase, and relative amplitude.
In the normal operating mode (see the next section), the MEBT forms a pre-defined bunch pattern from the initially CW beam coming from RFQ by removing 80% of bunches. It is accomplished by the MEBT chopping system, which consists of two broadband kickers [3] and an absorber built inside the same vacuum chamber. In the space between the first kicker and the absorber, marked as region B in Fig. 1, trajectories of adjacent bunches can differ significantly depending whether the bunches are scheduled to be removed or passed. The BPM system needs to be capable of resolving these trajectories for commissioning of the chopping system.

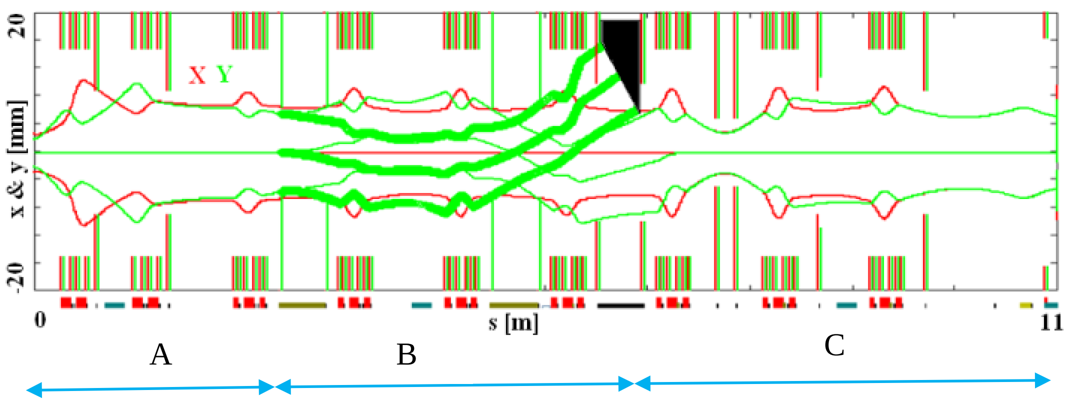

Figure 1: Scheme of MEBT optics [2]and the beam envelope. The thin red and green lines are the central trajectory and 3σ envelope ($\varepsilon_{rms_}$n=0.25 mm mrad) of the passing bunches (red – X, green – Y), and the thick green lines are the Y envelope of the chopped-out bunches. Rectangles below the plot represent quadrupoles in red and bunching cavities in blue. BPMs are inside of each doublet or triplet.

This specification indicates the beam parameters and the nominal MEBT modes, for which the BPM parameters are specified; describes mechanical constrains; and establishes the BPM requirements.

3 Key Assumptions, Interfaces & Constraints:

The MEBT BPMs designs shall conform to the Fermilab Engineering Process [5] and ES&H Standards [6].

3.1 Beam parameters

Typical beam parameters in MEBT BPMs are listed in Table 1.

Table 1. Typical beam parameters

Ion type	H-
Beam energy	2.1 MeV
Particles per bunch, nominal (range)	$2 \cdot 10^8$ ($0.2 \cdot 10^8$ - $4 \cdot 10^8$)
Beam rms size, X/Y	3/3 mm
Bunch rms length	10º (162.5 MHz)
Bunch frequency at MEBT entrance	162.5 MHz CW

3.2 MEBT modes

To describe the MEBT modes, the following definitions are used:

Period: Determines the periodicity of MEBT bunch chopping pattern. Nominal value is 256 RF 162.5 MHz buckets (period ≡ 1575 ns)

Bunch: Filled 162.5 MHz bucket

Batch: continuous train of bunches

The relevant nominal MEBT modes are as follows.

3.2.1 Mode 1. Nominal operating mode

In the operating mode, the beam has different structures in three spacial regions as depicted in Figure 1:

A) Beam from RFQ exit to 3rd BPM: CW[§] 162.5 MHz, 5 mA average current

B) In the middle, from 3rd to 5th BPMs, all buckets are filled but bunches scheduled to be removed and passed have different vertical offsets. The maximum difference in Y-positions of neighboring bunches in a BPM is 10 mm.

C) The beam is chopped to create the required structure at the MEBT exit (starting from the 7th BPM) with periodicity of 256 RF buckets and the average current of 1 mA.
The nominal structure is described in Ref. [7] and is presented pictorially in Fig.2. To distinguish it from a true CW, in this document it is referred as "repetitive structure" (RS).

[§] The bunch sequence is interrupted for 1 period (1.575 μs) every 1000 periods (1.575 ms) by the LEBT chopping system for ion clearing in MEBT.

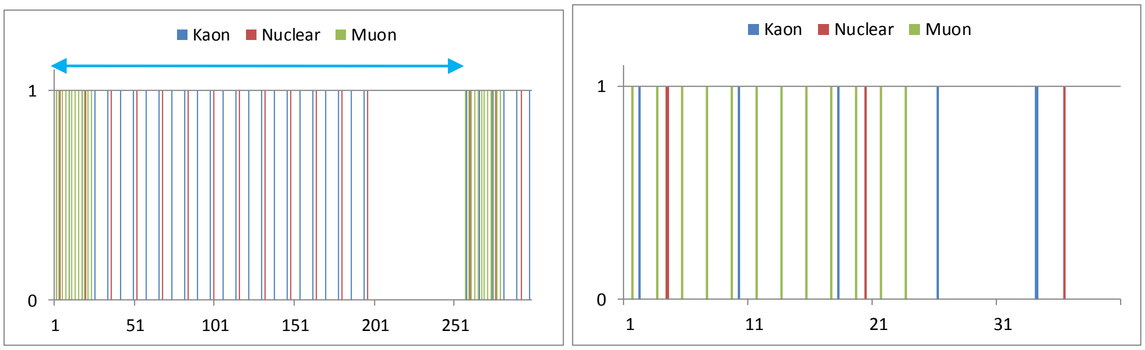

Figure 2: The bunch structure at the exit of MEBT in the nominal operating mode. Left: the arrow indicates the full period. Right: details of the beginning of the period. The horizontal axis is numbered according to the bucket number.

3.2.2 Mode 2. Pulse mode

The beam is chopped in LEBT for commissioning and diagnostics purposes.
Frequency of batches - 60 Hz
Rise and drop times of intensity in the batch[§] - ~100 ns
Flat top - 25.2 μs (16 periods)

The MEBT kickers can be either on or off, with the corresponding difference of trajectories as in Mode 1.
[§] Transverse position of bunches partly removed in LEBT may differ ~1 mm from those at the flat top.

3.2.3 Mode 3. Pre-chopped repetitive structure

The beam is pre-chopped in the LEBT to the nominal average current of ~1mA. The mode can be used for the thermal test of the MEBT absorber, preliminary tests of SRF, or together with MEBT chopping system in a case of temporary limitations on the duty factor of the latter.
Frequency of batches - 635 kHz (same period)
Rise and drop times of intensity in the batch[§] - ~100 ns
Flat top - 35 buckets (215 ns)
The MEBT kickers are off at the flat top.
[§] Transverse position of partly removed bunches may differ ~1 mm from those at the flat top.

3.2.4 Mode 4. Synchronous detection in the Repetitive Structure mode

Identical to Mode 1 but bunch parameters (either the transverse position or intensity) are slightly modulated in the frequency range of 100 Hz to 100 kHz. Typical transverse modulation is ~0.1 mm, typical longitudinal modulation of ~1 deg., and typical intensity modulation is ~10^{-7}. The mode is used for non-invasive diagnostics.

3.3 Mechanical constrains

The BPM assembly is installed between the quadrupoles of each doublet and triplet [8]. In the case of a triplet, it is placed between the central and downstream quadrupoles. The space available to a single BPM is depicted in Figure 3 as the *space free of winding*. Additionally, the space available for the four SMA cables for the BPM is 20mm, which is the spacing between the brown dashed lines.

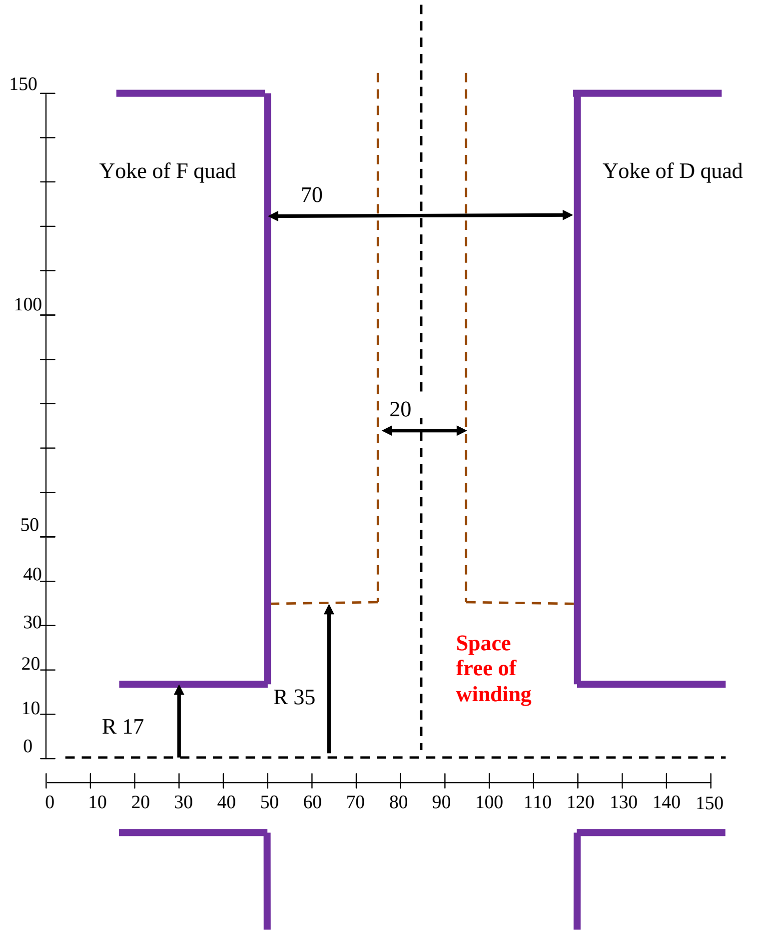

Figure 3. Space between quadrupoles that should be left free of winding for BPMs. All dimensions are in mm. The sketch shows the downstream portion of the triplet; restrictions in the doublets are identical.

Other miscellaneous components not stated in this document must fit in the *space free of winding* zone and in between consecutive coil to coil spacing between quadrupoles.
The BPM housing is welded to 1 ¼" OD tubes. The entire assembly will be suspended between the poles of the quadrupoles.
To allow for assembling, servicing, and baking of the BPMs, the quadrupoles can be disassembled into halves.

3.4 Temperature

The ambient temperature is 25 ±2ºC. The operating temperature at the BPM pickup location can be as high as 80C (heated by the quadrupoles).

4 Requirements

4.1 Dimensions

ID (minimum diameter of free space) - 30 mm
Radius of good area (maximum deviation of the beam centroid from the BPM electrical center) - 5 mm
Deviation of electric and mechanical centers - < 0.5 mm

4.2 Positioning of the pickups

4.2.1 <u>Accuracy</u>

Transverse - 0.5 mm
Longitudinal - 5 mm
Roll - 1º
Pitch, yaw - restricted by vacuum chamber alignment

Longitudinal positions of the electric centers of all BPMs with respect to the first MEBT BPM shall be measured within 0.5 mm.

Remaining errors will be compensated in software.

4.2.2 <u>Stability with respect to quadrupoles</u>

Sub – minute time scale (i.e. vibration)
Transverse - 0.005 mm
Longitudinal - 0.1 mm

Long – term, with following conditions:
Time scale - week
Temperature of the pickup 23 – 80 C
Temperature of the mounting frame 23 – 27 C
Internal pressure 0 - 1 atm

Transverse - 0.05 mm
Longitudinal - 0.5 mm
Roll - 0.2º

4.3 Measurement requirements

Accuracy and precision are specified only for buckets filled with the nominal number of particles.
As pointed out in section 3.2.1, positions of neighboring bunches can differ by up 10 mm in the region B of Figure 1, and their intensity vary from full to zero in the region C, if the MEBT kickers are on.

4.3.1 Phase measurements

The phase is measured to determine the beam energy from time-of-flight and to phase the bunching cavities.
Phase is measured in degrees of 162.5 MHz (1º = 0.01709ns).

Table 2. Phase measurement requirements.

	Mode 1. CW-to-RS	Mode 2. Pulse mode	Mode 3. Pre-chopped RS	Mode 4. Sync. detection
Report frequency	10 Hz	10 Hz	10 Hz	1 Hz
Phase accuracy[§]	3º	5º[§§]	3º	
Phase precision[§§§], rms	1º	2º[§§]	1º	0.01º [§§§§]

[§] For modes 1 -3, the absolute accuracy of phase measurements is specified relative a reference BPM (the first BPM in the MEBT). In the Mode 4 (Synchronous detection in the Repetitive Structure mode), the phase is reported relative to its unperturbed value.

[§§] When the MEBT kickers are turned off. The data are averaged over the pulse flattop only.

[§§§] The BPMs will be used, in part, for phasing of the bunching cavities in Mode 2. In this process, the bunch length will increase to 45º (rms).

[§§§§] For typical phase deviation of ~1º.

4.3.2 Position measurements

The BPM system reports in two regimes, “trajectory” and “bunch-by-bunch”.

In the trajectory regime, all BPMs report the data averaged over all bunches. This regime is used for routine tuning of trajectories during operation and for optics measurements.

In the bunch-by-bunch regime, a selected BPM reports data for each bucket position within the period. There shall be 5 BPMs capable of reporting in this mode (starting from the first BPM after the first MEBT kicker and ending by the second BPM after the absorber). This regime is used for chopping system commissioning.

The requirements are listed, correspondingly, in Table 3 and Table 4.

Table 3. Position measurement requirements in trajectory regime.

	Mode 1. CW-to-RS	Mode 2. Pulse mode	Mode 3. Pre-chopped RS	Mode 4. Sync. detection
Report frequency	10 Hz	10 Hz	10 Hz	1 Hz
Position accuracy[§]	10 μm[§§]	30 μm[§§§]	10 μm	
Position precision, rms	5 μm[§§]	10 μm[§§§]	5 μm	1 μm[§§§§]
Stability (week)	20 μm	20 μm	20 μm	

[§] In the Mode 4 (Synchronous detection in the Repetitive Structure mode), the position is reported relative to its unperturbed value.

[§§§] Excluding the region with two trajectories (labeled B in Figure 1).

[§§§] When the MEBT kickers are turned off. The data are averaged over the pulse flattop only.

[§§§§] For typical position deviation of ~0.1 mm.

Table 4. Position measurement requirements in bunch-by-bunch regime.

	Mode 1. CW-to-RS	Mode 2. Pulse mode
Report frequency	1 Hz	1 Hz
Position accuracy	100 μm	200 μm
Position precision, rms	30 μm	60 μm

4.3.3 Intensity measurements

Intensity is not calibrated in absolute units and is used only for comparison, depending on the regime, between BPMs or between buckets. The report frequency is the same as for the position measurements.

In Modes 1 -3, the intensity measurements are used to control beam scraping.
Intensity precision, rms 5%

In the Mode 4 (Synchronous detection in the Repetitive Structure mode), intensity measurements are used for laser diagnostics.
Intensity precision, rms 10^{-7}

5 References:

Documents with reference numbers listed are in the Project X DocDB: http://projectx-docdb.fnal.gov

[1] Project X and PXIE MEBT Functional Requirements Specification Document #: Project-X-doc-938

[2] PXIE Optics and Layout, by V. Lebedev, S. Nagaitsev, J.-F. Ostiguy, A. Shemyakin, B. Shteynas, N. Solyak, Proc. of IPAC'12, New Orleans, USA, May 20 - 25, 2012, THPPP057

[3] PXIE MEBT kicker functional requirements specification, Document #: Project-X-doc-977

[4] Functional specifications for PXIE MEBT absorber, Document #: Project-X-doc-964

[5] Fermilab Engineering Manual http://www.fnal.gov/directorate/documents/FNAL_Engineering_Manual.pdf

[6] Fermilab ES&H Manual http://www-esh.fnal.gov/pls/default/esh_home_page.page?this_page=15053

[7] PXIE Functional Requirements Specification, Document #: Project-X-doc- 980

[8] PXIE MEBT Quadrupoles Functional Requirements Specification, Document #: Project-X-doc- 933