PIP-II MEBT Kicker Assembly

Technical Requirements Specification

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**Document Approval**

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# Purpose

A TRS describes.

# Introduction

The PIP-II MEBT kicker assembly is a part of the MEBT chopping system, which will prepare a pre-specified bunch structure of the 2.1 MeV H- beam for further acceleration. A significant fraction of the bunches coming out of the RFQ are directed to the absorber and the remaining ones are transported to the SRF linac.

Two travelling-wave kicker structures working synchronously deflect the beam when equal and opposite polarity voltage is applied to the two opposing electrodes of each kicker structure. Affected bunches, lost to the absorber, are labeled “removed” bunches. Otherwise, the beam propagates unaltered (“passing” bunches).

# Scope

In this TRS, the kicker assembly performance requirements are presented. They emanate from the MEBT kicker system FRS [6] and cover the mechanical structure including loads and protection electrodes, and the driver electronics. The main components of the kicker structure are the electrodes in the form of two helix sub-assemblies mounted on one side of the vacuum enclosure. The driver electronics provide the electromagnetic pulse to the electrodes and are based on fast HV switches. The loads at the downstream end of the helices provide the capability of measuring the waveform experienced by the structure. The protection electrodes are located at both ends of the kicker structure and protect it from beam scraping.

# Acronyms

|  |  |
| --- | --- |
| CDR | Conceptual Design Report |
| FESHM | Fermilab ES&H Manual |
| FRCM | Fermilab Radiological Control 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  |
| RF | Radio Frequency |
| SCD | System Configuration Document |
| SRF | Superconducting Radio-Frequency |
| TC | Teamcenter |
| TRS | Technical Requirements Specification |
| WBS | Work Breakdown Structure |

# Reference

|  |  |  |
| --- | --- | --- |
| **#** | **Reference** | **Document #** |
| 1 | PIP-II MEBT Kicker EPDM | ED0001271 |
| 2 | Installation and Commissioning (WBS 121.4) System Configuration Document (SCD) | ED000xxxx |
| 3 | [Fermilab Engineering Manual](http://directorate-docdb.fnal.gov/cgi-bin/RetrieveFile?docid=34) | NA |
| 4 | [Fermilab Environmental Safety and Health Manual](http://eshq.fnal.gov/manuals/feshm/) | NA |
| 5 | Fermilab Radiological Control Manual | NA |
| 6 | PIP-II MEBT Kicker System Functional Requirements Specification (FRS) | ED0001305 |
| 7 | PIP-II Conceptual Design Report | ED0006203 |

# Key Assumptions & Constraints

The technical requirements for the kicker assembly largely depend on the beam parameters (table below) expected at the location of the kickers and absorber, hence of the optical design of the MEBT line.

|  |  |  |
| --- | --- | --- |
| **Parameter** | **Value** | **Unit** |
| Ion type | H- |  |
| Beam (kinetic) energy | 2.1 (±1%) | MeV |
| Beam velocity (**) | 0.0668 |  |
| Macro-pulse length | 0.55 | ms |
| Macro-pulse repetition rate | 20 | Hz |
| Frequency of bunches (within macro-pulse) | 162.5 | MHz |
| Nominal charge per bunch at the exit of the MEBT\* | 30 | pC |
| Transverse bunch size, 6*x/y* (horizontal/vertical) | 16/12 | mm |
| Bunch length, 6*z* | 1.3 | ns |

\*= 4.9 mA averaged over one RF period at 162.5 MHz

Each kicker assembly must be contained between two quadrupole triplets. Consequently, the physical length of the kicker assembly, including the vacuum enclosure, is 650 mm or less (flange-to-flange).

It is assumed that the 0.55 ms-long macro-pulse is generated by the LEBT chopper.

Other constraints are mainly dictated by beam loss requirements downstream, in the MEBT and beyond. They can be summarized with the following two restrictions:

* Beam loss (in the MEBT) of the “passing” bunches <5%
* Relative residual charge of the “removed” bunches (at the exit of the MEBT) <5×10-3

Finally, in accordance with the emittance budget assumed in the CDR [7], emittance dilution of the “passing” bunches should be <10%.

# Requirements

Full deflection is defined as the separation between the “passing” and “removed” bunches in the transverse (vertical) direction by 6*y*, where *y* is the vertical rms beam size at the absorber. Based on the assumptions and constraints above, the basic requirement for each kicker assembly to deflect the trajectory of the beam by 7.4 mrad [6] translates into a voltage difference of 1 kV between opposing electrodes considering an effective electric length of 500 mm and a gap of 16 mm.

The voltage of ±500 V is applied to the kicker assembly electrodes to deflect the beam onto a trajectory that eventually intercepts the absorber surface (when both kicker assemblies are used together). When the voltage difference is set to zero, the beam trajectory avoids the absorber surface and bunches reach the first SRF cryomodule.

Thus, the kicker assembly requirements are summarized in the table below.

|  |  |  |
| --- | --- | --- |
| **Requirement** | **Value** | **Units** |
| *Dimensions* |
| Effective electric length | 500 | mm |
| Distance between opposite plates/electrodes | 16 | mm |
| Tolerance for the distance between opposite plates/electrodes | ±0.5 | mm |
| Minimum protection electrodes height (vertical direction) | 30 | mm |
| Minimum protection electrodes width (horizontal direction) | 30 | mm |
| Protection electrodes’ slit height (vertical direction) | 13 | mm |
| Minimum protection electrodes’ slit width (horizontal direction) | 20 | mm |
| *Electrical properties* |
| Helix sub-assembly impedance | 200 |  |
| Tolerance for the helix sub-assembly impedance | ±5 |  |
| Loads impedance | 200 |  |
| Tolerance for the loads impedance | ±2 | % |
| Loads’ nominal power rating (average) | 1.5 | kW |
| Loads’ peak power rating | 1.5 | kW |
| Loads output impedance | 50 |  |
| *Pulse* |
| Nominal voltage amplitude for full deflection*\** (i.e. “removed” bunches) | ±500 | V |
| Voltage amplitude for “passing” bunches | 0 | V |
| Minimum length of time with electrodes at zero voltage between pulses maxima/minima (with respect to the bunch center) | ±0.65 | ns |
| Voltage tolerance at zero voltage between pulses over 1.3 ns (i.e. ±0.65 ns with respect to the bunch center) | ±30 | V |
| Minimum switching (0 to ±500V) frequency averaged over one macro-pulse period (i.e. 50 ms) | 500 | kHz |
| Minimum ‘instantaneous’ switching frequency*#* | 81.25 | MHz |
| Phase velocity tolerance (w.r.t. beam velocity matching) | ±1 | % |
| *Beam irradiation resistance* |
| Minimum averaged heat-load that the kicker electrodes should withstand | 40 | W |
| Minimum accidental beam loss that the kicker electrodes should withstand*†* | 20 | J |
| Minimum steady-state irradiation from H- beam losses for which the kicker structure should not deteriorate*£* | 20 | A |
| Minimum averaged heat-load from the beam that *each* protection electrode should withstand | 40 | W |
| Minimum accidental beam loss that *each* protection electrodes should withstand | 20 | J |
| *Vacuum* |
| Typical operation vacuum | 2×10-7 | Torr |
| Maximum outgassing from the kicker assembly under operational conditions | 1×10-6 | Torr∙l/s |

*\** Ideal case of two infinite parallel plates. Any reduction of the integral kicker strength resulting from the actual geometry of the kicker structure is to be compensated by increasing the applied voltage by the corresponding amount.

*#* Any bunch of the 162.5 MHz macro-pulse train can either pass or be removed.

*†* This loss is assumed to be evenly distributed along the entire length of the kicker and on one side only.

*£* Losses are assumed to be from the tail of the particles distribution.

In addition to the requirements listed in the table, the kicker assembly design shall satisfy the following:

1. The direction of the deflection shall be vertical.
2. Any difference between the kicker phase velocity and beam velocity shall be corrected by increasing the passing bunches’ voltage amplitude (i.e. null voltage) duration by a corresponding amount.
	1. For example, for a rectangular pulse, a 1% velocity error should be compensated by increasing the null voltage duration by 0.25 ns.
3. Any reduction of the integral kicker strength due to field non-linearity at the periphery of the horizontal beam size, X = ±8 mm, shall be compensated by increasing the applied voltage by the corresponding amount.

# Safety Requirements

The system shall abide by all Fermilab ES&H (FESHM) and all Fermilab Radiological Control Manual (FRCM) requirements including but not limited to:

|  |
| --- |
| 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
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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.

In addition, 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 |

In cases where International Codes and Standards are used the system shall follow FESHM Chapter 2110 Ensuring Equivalent Safety Performance when Using International Codes and Standards and requires the approval and authorization of the PIP-II Technical Director or designee.

Additional Safety Requirements that are not listed in the general list above shall be included in the Requirements table in the Functional Requirements section.