PIP-II Dipole Magnet

Technical Requirements Specification

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**Document Approval**

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# Purpose

There will be 37 horizontal bending (regular) dipoles and two vertical bending dipoles in the Linac to Booster transfer line for PIP-II. This TRS will specify the magnet requirements. There are three different styles of dipoles; 36 regular dipoles, one wide aperture regular dipole (this is the first dipole and needs to accommodate both the bent beam as well as a straight ahead beam for when the dipoles are off) and two vertical bending dipoles.

# Scope

WBS Dictionary Definition for the BTL MagPS: Design, procurement, fabrication, and testing of all types (dipoles, quads, correctors, special) of magnets and power supplies in the beam transfer line. This specific TRS addresses the functional requirements of the dipole power supplies in the BTL Line and includes requirements for the raw power supply and the regulation requirements. There are four independent power supply systems described.

# Acronyms

|  |  |
| --- | --- |
| FESHM | Fermilab ES&H Manual |
| FRCM | Fermilab Radiological Control Manual |
| FRS | Functional Requirements Specification |
| TRS | Technical Requirements Specification |
| L2 | WBS Level 2 |
| L3 | WBS Level 3 |
| PIP-II | Proton Improvement Plan II Project  |
| SCD | System Configuration Document |
| TC | Teamcenter |
| WBS | Work Breakdown Structure |
| BTL | Beam Transfer Line |
| EPDM | Engineering Process Document Management |
| NPT | National Pipe Thread |

# Reference

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| **#** | **Reference** | **Document #** |
| 1 | EPDM | ED0005433 |
| 2 | [Fermilab Engineering Manual](http://directorate-docdb.fnal.gov/cgi-bin/RetrieveFile?docid=34) | NA |
| 3 | BTL Dipole FRS | NA |
| 4 | BTL Dipole Magnet Preliminary Design | NA |
| 7 | Physics Driven Requirement | ED001026 |

# Key Assumptions

It is assumed that the dipole magnets will be delivered complete with water manifolds and a beam tube It is also assumed that these magnets will be capable of DC operation at 1000 MeV .

# Technical Requirements

The requirements for the dipole magnets are shown below in table 6-1. While it may be advantageous to build all these magnets the same, the “first” magnet in the string will need to have a wide enough aperture to allow for both the bent beam as well as a straight-ahead beam (which must have a small enough field to not perturb the beam beyond what can be corrected for). The nominal displacement of the beam through the dipole is 147.6 mm and so this magnet may require a special beam tube

Table ‑. Regular Magnet Requirements

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| --- | --- |
| **Requirement #** | **Requirement Statement** |
|  T-D-121.03.05-A001 | Effective length of the regular dipoles is 2.45 m |
|  T-D-121.03.05-A002 | Physical length of the regular magnets (from end of beam tube to end of beam tube) shall not exceed 3.1 m |
|  T-D-121.03.05-A003 | The regular dipole gap shall be 52 mm |
|  T-D-121.03.05-A004 | Minimum beam tube aperture shall be 46 mm |
|  T-D-121.03.05-A005 | The regular dipole shall have a good field region such that there is a good field region with a diameter of 24 mm centered on the beam trajectory  |
|  T-D-121.03.05-A006 | The regular dipole uniformity shall be better than dB/B=.02% |
|  T-D-121.03.05-A007 | The regular dipole maximum field (for a current = 500 amps) shall be .277 Tesla with a nominal field at 800 MeV of .229 Tesla |
|  T-D-121.03.05-A008 | The regular dipoles shall be capable of DC operation at 500 amps |
|  T-D-121.03.05-A009 | The regular dipoles shall be capable of ramping at a maximum rate of .006 T/sec (10 Amps/sec) |
|  T-D-121.03.05-A010 | The regular dipoles shall not exceed transverse dimensions of 400 mm width and 300 mm height |
|  T-D-121.03.05-A011 | The regular dipoles shall have a nominal integrated field of .561 T-m and a nominal bend angle of .115 radians |
| T-D-121.03.05-A012 | The regular dipole coils shall be continuous (no splices) |
| T-D-121.03.05-A013 | The regular dipoles shall have eight alignment fiducials welded to the steel; 2 on top of each end and 1 at each end on the sides of the magnet on the midline of the magnet |
| T-D-121.03.05-A014 | All dipole magnets shall be hipotted to 2500 volts DC with less than 1 micro amp of current |

Since the nominal beam energy is 800 MeV the regular dipoles provide a nominal bend of .1205 radians. This means that one dipole will displace the beam by 147.6 mm. There are two designs possible: 1) design a magnet with a sagitta that follows the beam (sagitta of 36.9 mm) or design a rectangular magnet with a large enough pole tip (the beam pipe then would be curved to follow the beam). The sagitta is calculated from .5\*L\*Tan (Ɵ/4).

Table ‑. First Dipole Magnet Requirements

This magnet can be a C-magnet, a Lambertson or be the same as a regular dipole but with a wider aperture:

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| **Requirement #** | **Requirement Statement** |
|  T-D-121.03.05-B001 | This magnet shall have the same magnetic and water properties as the regular dipoles properties |
|  T-D-121.03.05-B002 | This magnet shall have both a straight ahead and a beam line beam tube  |
|  T-D-121.03.05-B003 | The beam pipe at the ends of the magnet must be circular and have the same properties as the regular dipole magnet beam pipe |
|  T-D-121.03.05-B004 | The field in the straight ahead beam pipe shall not exceed 1 mT |
|  T-D-121.03.05-B005 |  |

Table ‑3. EOL Dipole Magnet Requirements

The End Of Line Dipoles will bend beam vertically for injection into the Booster Accelerator. There are two such magnets required.

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| **Requirement #** | **Requirement Statement** |
|  T-D-121.03.05-C001 | Maximum effective length of the EOL dipoles is 1.8 m |
|  T-D-121.03.05-C002 | Physical length of the EOL magnets (from end of beam tube to end of beam tube) shall not exceed 2.2 m |
|  T-D-121.03.05-C003 | The EOL dipole gap shall be 52 mm |
| T-D-121.03.05-C004 | Minimum beam tube aperture shall be 46 mm |
|  T-D-121.03.05-C005 | The EOL dipole shall have a good field region such that there is a good field region with a diameter of 24 mm centered on the beam trajectory  |
|  T-D-121.03.05-C006 | The EOL dipole uniformity shall be better than dB/B=.02% |
|  T-D-121.03.05-C007 | The EOL dipole maximum field integral (for a current = 500 amps) shall not exceed .292 T-m |
|  T-D-121.03.05-C008 | The EOL dipoles shall be capable of DC operation at 500 amps |
| T-D-121.03.05-C009 | The EOL dipoles shall have a maximum magnetic field of less than .24 T |
|  T-D-121.03.05-C010 | The EOL dipoles shall be capable of ramping at a maximum rate of .006 T/s (10 Amps/sec) |
|  T-D-121.03.05-C011 | The EOL dipoles shall not exceed transverse dimensions of 400 mm width and 300 mm height |
|  T-D-121.03.05-C012 | The EOL dipoles shall have nominal bend angle of .0517 radians |
| T-D-121.03.05-C013 | The EOL dipole coils shall be continuous (no splices) |
| T-D-121.03.05-C014 | The EOL dipoles shall have eight alignment fiducials welded to the steel; 2 on top of each end and 1 at each end on the sides of the magnet on the midline of the magnet |
| T-D-121.03.05-C015 | The EOL dipole beam tube may have a rectangular beam tube large enough to contain 6 sigma beam throughout the magnet and that connects to a circular beam tube outside the magnet. |
| T-D-121.03.05-C016 | The EOL Dipole beam pipe, if circular, must have a sagitta in the vertical dimension of 20.5 mm |

Table ‑3. Magnet Water Requirements

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| **Requirement #** | **Requirement Statement** |
|  T-D-121.03.05-D001 | All external water connections shall be appropriately sized female NPT fittings |
|  T-D-121.03.05-D002 | The maximum water pressure drop is 80 psid at the operating flow |
|  T-D-121.03.05-D003 | Water flow velocity in the magnet coils shall be between 5 and 8 feet per second |
| T-D-121.03.05-D004 | Water temperature rise shall not exceed 10 degrees C above the nominal 35 degrees C water temperature ( 5.5 degrees F) |
| T-D-121.03.05-D005 | Nominal inlet water temperature is 95 degrees F (35 degrees C) |

Table ‑4. Magnet Vacuum Requirements

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| **Requirement #** | **Requirement Statement** |
| T-D-121.03.05-E001 | All dipole magnets will have beam tubes installed |
|  T-D-121.03.05-E002 | Beam tube material shall be either 316 or 304L stainless steel |
| T-D-121.03.05-E003 | The ends of the beam tube shall extend 3” from the ends of the external coils |
| T-D-121.03.05-E004 | The ends of the beam tube shall be clean cut and perpendicular to between .005” to .010” |
| T-D-121.03.05-E005 | The beam tube for the regular dipoles shall be circular with a OD of 2” and a wall thickness of .063. |
| T-D-121.03.05-E006 | The beam tube shall be degreased and cleaned as per spec # xxx-MSD-xxxx |
| T-D-121.03.05-E007 | The beam tube for the regular dipoles shall have a sagitta of 36.9 mm for the regular dipoles |

Table ‑5. Magnet Support Structure Requirements

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| **Requirement #** | **Requirement Statement** |
|  T-D-121.03.05-F001 | All dipoles shall have three feet for mounting that are welded to the body of the magnet; these feet will be located 22% of the length from each end |
| T-D-121.03.05-F002 | All magnets shall have provisions to allow for rigging the magnet; this could be tapped holes of an appropriate size to allow for swivel hoist rings that are appropriate for the magnet load with a safety margin |

# 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:

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| Electrical Safety |
| * FESHM Chapter 9110 Electrical Utilization Equipment Safety
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| * FESHM Chapter 9160 Low Voltage, High Current Power Distribution Systems
 |
| * FESHM Chapter 9190 Grounding Requirements for Electrical Distribution and Utilization Equipment
 |
| Pressure Piping safety |
| * FESHM Chapter 5031.1 Piping Systems
 |
| General Safety |
| * FESHM Chapter 2000 Planning for Safe Operations
 |

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:

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| --- |
| NFPA 70 – National Electrical Code |
| IEC Standards for Electrical Components |
| ASME BPVC Section IX Qualification Standard for Welding, Brazing and Fusing Procedures |

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.