Booster Injection Girder Design for PIP-II

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March 13, 2018
PIP-II Technical Meeting
Injection Girder Design Assumptions/Constraints

- New injection beam power 17-18 kW - factor 7-8 above today:

- Foil thickness now 380 ug/cm² with 0.1% loss (~2W) increase thickness to get 0.2% H0 loss -> ~ 35 Watts

- Assume 4 bump design to direct waste beam away from aperture (major waste beam 0.1 to 0.2% H0)

- Current flange-flange long straight 5.68 m TRY TO EXPAND TO 6.68 m (keep GM bend center fixed)
  - If this doesn’t work how much do we need and how to accomplish

- Must fit in the following elements
  - Orbump magnets (4) \( L = 0.616 \) m f-f
  - Foil assembly (1) \( L = 0.3048 \) m f-f
  - Absorber (1) \( L = 0.6 \) m f-f (0.3m tungsten absorber)
  - Harmonic/dipole corrector (1) \( L = 0.4826 \) m f-f
  - Vertical painting kicker (2 within SS & 2 between F&D GMAG) \( L = 0.2546 \) m-f (look at alternative locations)
  - Vacuum bypass (will use drift space between orbumps)
  - Drift space between orbumps

- Must be able to bring beam in vertically above DGRAD magnet \( \rightarrow 6.5'' (165mm) \) half height

- \textbf{Bmax ORBUMP now 3.0 kG how much can we go? To 4.0 kG? -→ this is key in determining length SS.}

- Assume (for now) gradient magnet reduced length by 1 m from 2.88612 to 1.88612 m arc length
Existing Straight Section

5.68 m (f-f)

ORBUMPS

Harmonic corrector

BPM

vacuum bypass

Inj beam

foil changer

diagnostics
Parameters for D Gradient magnet PIP 1+

Booster Gradient Magnet Replacement Specifications

Purpose: To allow the increase of long straights in the Booster where necessary.
Injection region for a larger girder that can accommodate higher energy injection.
Extraction region to allow greater separation of doglegs and allow the septa magnet to be raised.

Parameters:
Beta beating will not increase from our present level estimated to be about 8%.
A working specification is that replacement magnet(s) will not have a notable impact or be less than
1% of our present beta beating.
The working length has been set as follows:
Physical length: 1.8896 m
Path length: 1.889 m
Bending angle: 0.060 radians

Apertures will be no smaller than our present magnets in the vertical plane of 2.24 inches at beam
center.
A working specification is that the new gradient magnet will be between 2.5 and 3 Inches.

Higher order fields quality will be no worse than our present magnets which have been documented in
Specifications # 0321-ES-2540, TM -0695, TM-0695 Addendum.
Working Tune Qx: 6.653 and Qy 6.801
A working specification is that the dipole and quadrupole fields will be linear to 1% across beam
aperture. The coefficients for both body and integral at reference radius corresponding to beam center
shall not exceed +/- 1 unit.
**Beta beat compensated for by gradient magnet pole tip shape**

**Beta beat requires harmonic correctors in addition to pole tip shape.**
Potential Vertical painting magnet locations

L01 Short straight

Flange-flange 0.8804 m
Corr = .432 -> free = 0.4486 m

LO5D Mini-straight

Flange-flange 0.1804 m
Must increase to use for Ver. Paint magnet
ORBUMP – Key to girder design

- Best ferrite CDM10 with Bs=0.46T
- Current Peak field 0.3 T
- Can we increase? Probably, but by how much?

- Increase current and/or reduce gap
  - Ferrite saturation & drop in field homogeneity
- Multi-turn conductor (1->2)?
  - NO increase inductance / voltage
- Other materials?
  - Finemet -> conductive and very expensive

- Look at SS length for 3, 3.5, and 4 kG

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\int B y dl @ 15 , kA$</td>
<td>0.1676</td>
<td>T-m</td>
</tr>
<tr>
<td>Ferrite length</td>
<td>523.3</td>
<td>mm</td>
</tr>
<tr>
<td>Effective length</td>
<td>558.5</td>
<td>mm</td>
</tr>
<tr>
<td>Aperture gap</td>
<td>65.1</td>
<td>mm</td>
</tr>
<tr>
<td>Aperture width</td>
<td>135.1</td>
<td>mm</td>
</tr>
<tr>
<td>Inductance</td>
<td>1.83</td>
<td>$\mu \text{H}$</td>
</tr>
<tr>
<td>Resistance</td>
<td>$&lt;1$</td>
<td>m$\Omega$</td>
</tr>
<tr>
<td>Quadrupole</td>
<td>$1\times10^{-4}$</td>
<td>mm$^{-1}$</td>
</tr>
<tr>
<td>Diff</td>
<td>Painting</td>
<td>Shift</td>
</tr>
<tr>
<td>------</td>
<td>----------</td>
<td>-------</td>
</tr>
<tr>
<td>0.006</td>
<td>0.4994</td>
<td>0.125</td>
</tr>
</tbody>
</table>

**Booster Injection PIP II**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>2/22/2018</td>
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</tr>
</tbody>
</table>

**Accumulation**

- **Start**: 0.00000000
- **End**: 13.37938117

**Distance**

- **SB**: 0.0847094 0.42870940
- **FMAGU**: 2.88961 3.48961000
- **GMAGF**: 0.1712906 0.60000000
- **FMAGD**: 2.45917117 2.13961 3.63788057
- **VPK2**: 0.2038 3.92251940
- **ORB1**: 0.2455 7.08099057
- **ORB2**: 0.2455 9.13699057
- **ORB3**: 0.2455 10.12029057
- **ORB4**: 0.2455 12.17629057

**DRIFT**

- **DMAGU**: 0.5 0.1204 4.06831940
- **DMAGD**: 0.5 0.1204 15.78766174

**PMG2**

- **ORB1**: 0.2455 6.83549057
- **ORB2**: 0.2455 9.13699057
- **ORB3**: 0.2455 10.12029057
- **ORB4**: 0.2455 12.17629057

**VPK**

- **ORB1**: 0.2455 3.48961000
- **ORB2**: 0.2455 6.83549057
- **ORB3**: 0.2455 9.13699057
- **ORB4**: 0.2455 12.17629057

**Injection**

- **PIP II**

**Cut Length**

- **L/2**: 0.3048 0.616
- **B**: 3.578737271
- **d**: 0.4318 0.2546
- **L0**: 6.6806
- **θ**: 0.036

**Diff from 6.68**

- **L**: 0.4318
- **d**: 0.2546
- **L0**: 6.6806
- **θ**: 0.036
Assume 11mm vertical paint

Vertical elevation of Gradient magnet (6.5” half height)

<table>
<thead>
<tr>
<th></th>
<th>3 kG</th>
<th>3.5 kG</th>
<th>4 kG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y1</td>
<td>72 mm</td>
<td>75 mm</td>
<td>72 mm</td>
</tr>
<tr>
<td>Y2 @ GM</td>
<td>165 mm</td>
<td>170 mm</td>
<td>168 mm</td>
</tr>
<tr>
<td>D1</td>
<td>1.8 m</td>
<td>1.5 m</td>
<td>1.2 m</td>
</tr>
<tr>
<td>ele @ORB</td>
<td>146 mm</td>
<td>148 mm</td>
<td>144 mm</td>
</tr>
<tr>
<td>SS len</td>
<td>7.4 m</td>
<td>6.8 m</td>
<td>6.2 m</td>
</tr>
</tbody>
</table>

2/22/2018 Booster Injection PIP-II dej
Reduce L by 0.75 m
With 0.25 m outside SS
0.5 m inside SS

Shift bend center 0.125 outward

**ORBUMP Parameters**

<p>| | |</p>
<table>
<thead>
<tr>
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<tbody>
<tr>
<td>ORB</td>
<td>3.58 kG</td>
</tr>
<tr>
<td>Y1</td>
<td>74 mm</td>
</tr>
<tr>
<td>Y2 @ GM</td>
<td>170 mm</td>
</tr>
<tr>
<td>D1</td>
<td>1.44 m</td>
</tr>
<tr>
<td>ele @ORB</td>
<td>147 mm</td>
</tr>
<tr>
<td>SS len</td>
<td>6.68 m</td>
</tr>
</tbody>
</table>
pk1_kick = 0.0020842958;
pk2_kick = -0.0009566012;
pk3_kick = -0.0007475904;
pk4_kick = 0.0018180551;

<table>
<thead>
<tr>
<th>Vertical painting magnet</th>
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<tbody>
<tr>
<td>y(paint)= 0.002 m</td>
</tr>
<tr>
<td>length 0.2038 m</td>
</tr>
<tr>
<td>Field 0.478999 kG</td>
</tr>
<tr>
<td>G 0.075 m</td>
</tr>
<tr>
<td>B 0.478999 kG</td>
</tr>
</tbody>
</table>
Assume gap = 55 mm then
Current ~ 15.66 kA
(current supply 15 kA)
Summary

- Major constraints:
  - Input beam to fit above upstream gradient magnet (hard constraint)
    - Unless we bore a hole or make an indentation
  - Want to keep Max field ORBUMP < 4 kG
  - Must fit in straight section length

- Have workable solution
  - 4 bump design
  - Straight section length 6.68m (1m larger than today)
  - 4 new BRBUMP magnets @ 3.58 kG (reduce gap from 65 to 55mm)
  - 2 new “D” gradient magnets (2.1396 m effective length)
  - Dedicated Vertical painting magnets (outside straight) in mini & short straight
  - Little beta beat

- Need to look at vacuum connections (quick disconnect vs conflat, etc)
- Need to start looking at gradient magnet & ORBUMP designs
- Re-start Absorber and shielding design