Fermilab Proton Source Report

Bob Webber

ICFA Mini-Workshop on High-Intensity, High Brightness Hadron Beams

*Beam Halo and Scraping*

Lake Como, WI

9/14/99
Fermilab Linac Parameters

- 200 MeV proton Linac built ~ 1969
- H⁻ upgrade in 1977
- 400 MeV upgrade in 1992
- 15 Hz hardware capability, variable beam pulse rate
- 45mA pulse current typical at 400 MeV
- variable beam pulse length, typically 10-30 microsec
- typical efficiency 10 MeV to 400 MeV ~ >95%
- typical operation ~ .5μA for 0.2kW
- present normal 400 MeV capability ~ 20 μamp for 8kW
  - 45mA @ 15 Hz @30 microsec
- accelerated >90mA (protons) during Jan. 1999 test
Linac Toroid and BLM Plot

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Linac Radiation Survey Data

Four typical surveys between 12/94 and 3/96, readings are ‘on contact’ several hours after beam off, running typically at 1-1.5 E16 per hour.

- 750 KeV
- 400 MeV
Linac Radiation and Activation Issues

- Linac radiation limits
  - several interlocked detectors for accident conditions
  - trips rarely encountered

- Linac activation
  - not a serious issue at typical levels
  - 400MeV “switchyard” is important
Fermilab Booster Parameters

- 400 MeV -- 8 GeV proton synchrotron built ~ 1970
- 15Hz sinusoidal magnet cycle with transition at $\gamma = 5.4$
- H- charge exchange injection, typically <12 turns
- adiabatic capture of injected beam by Booster RF
- 38 - 53 Mhz RF frequency, h=84
- typical 8 GeV beam current (1E16 pph = 0.44 $\mu$A)
  - historical high 3E12ppp @ 2.5Hz ~ 1.3$\mu$A for 10kW (8 GeV)
  - currently 2E12ppp @ 0.5Hz ~ 0.16$\mu$A for 1.3kW
  - Run II demand (2000) 5E12ppp @ .7 Hz ~ .55$\mu$A for 4.3kW
  - Year 2002 demand 5E12ppp @ 8 Hz ~ 6.4$\mu$A for 51kW
- typical efficiency 80% @ 1E12ppp to 60% @4E12ppp
Booster Low Intensity Charge Snapshot

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Digitizer saturation
Booster Radiation and Activation Issues

- Fermilab HEP program, within the coming year, will be limited by allowed radiation around Booster
  - demand for proton throughput will rise order of magnitude in next three years relative to historic levels in 90’s
  - recent office and beamline constructions and tightened radiation exposure regulations exacerbate original situation
  - little option for additional shielding
- Component activation will be a serious concern at NUMI/MiniBooNE levels
- Booster beam loss reduction and control key to entire future planned Fermilab high energy physics program!
Booster Ring Radiation Survey
24 hrs after extended running
at 7.5E15/hr

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Booster Extraction Area Survey 24 hrs after extended running at 7.5E15/hr
Readings are mR/hr @ 1 ft.
1998 Booster Shielding Assessment

- Driving factors
  - old assessment inadequate for anticipated proton requirements
  - re-location of extraction point for beam to Main Injector
  - old assessment relied on loss signature at few locations limiting machine development flexibility, e.g. high energy orbit changes and magnet moves

- Numerous soil activation measurements
- Complete shielding geometry assessment for entire ring
- Many measurements to understand radiation patterns and levels for “normal” and “accident” conditions
- Resulted in array of ~50 interlocked radiation detectors
### Typical Booster Lattice Period and Apertures

**Diagram:**
- Long Straight
- Short Straight
  - Defocus
  - Focus
  - Focus
  - Defocus
- 65 feet

<table>
<thead>
<tr>
<th>Location</th>
<th>Physical Aperture (inches)</th>
<th>$R$ Value (cm$^{1/2}$)</th>
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<tbody>
<tr>
<td></td>
<td>Horizontal</td>
<td>Vertical</td>
</tr>
<tr>
<td>Short-straight (BPM)</td>
<td>4.5</td>
<td>4.5</td>
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<tr>
<td>F-magnet (short-straight end)</td>
<td>4.5</td>
<td>1.64</td>
</tr>
<tr>
<td>F-magnet (D-magnet end)</td>
<td>8.0</td>
<td>1.64</td>
</tr>
<tr>
<td>D-magnet (F-magnet end)</td>
<td>8.0</td>
<td>2.24</td>
</tr>
<tr>
<td>D-magnet (long-straight end)</td>
<td>3.25</td>
<td>2.24</td>
</tr>
<tr>
<td>Long-straight (Beam pipe)</td>
<td>3.25</td>
<td>3.25</td>
</tr>
<tr>
<td>Long-straight (RF or Kicker)</td>
<td>2.24</td>
<td>2.24</td>
</tr>
<tr>
<td>Long-straight (Dog Legs)</td>
<td>2.31</td>
<td>3.25</td>
</tr>
<tr>
<td>Long-straight (Injection)</td>
<td>2.56</td>
<td>2.56</td>
</tr>
</tbody>
</table>

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Booster Shielding at Period Long 9

Sketch III
Typical Booster Tower
Applicable Detectors:
- Short 4
- Long 5 Short 5
- Long 6 Short 6
- Long 9 Short 9
- Long 10

Location of Chipmunk
PA Location of Protected Area

Longitudinal section
Transverse section
Outside of ring →

Short Position
- 9.2' PA
- 2.2'

Long Position
- 13.5'

Beam elevation 726.5'
- Magnet
- Magnet
- 8'
- Magnet
- Magnet

1998 Booster Shielding Assessment
Booster Department
1/8 inch = 1 foot

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Measured radiation levels at surface above Period 9 for different BLM ratios while attempting to lose all beam with dipole correctors.
Energy Dependent Loss Patterns

Measured radiation levels above periods 6 and 7 at different beam energies obtained by shutting off RF while accelerating.

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Booster Interlocked Radiation Detectors

Booster Interlock Detector Locations

- Unlimited Occupancy Buildings
- Minimal Occupancy Buildings
- Tunnels
- Stairwells and Labyrinths
- Indoor detector
- Outdoor detector
- Buried detector
- In Transformer Cabinet

Note:
- Booster Long 11 detector is located inside Brenford #3.
- Booster Short 13 is located in the CUB Utility Tunnel on the West side of the LCW Piping.
- Booster Short 12, located in the East Booster Fan Room, requires an AC-33 key.
- Booster Long 21, located in BGW-125, requires an AC-2 key.
- Booster Short 21, located in the Luminosity Upgrade Room, requires an AC-2 key.
- Booster Short 7 located in a manhole in the road between the Booster Towers.
- Booster Long 2 detector is located in the BPR1 transformer cabinet.
- The 8 Gev Line Scarecrow is located in the Tev enclosure.

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Causes of Beam Loss

- Poor orbit control
  - closed orbit changes dramatically vs. time in cycle
  - low field orbit is regularly modified by normal tuning
  - small dynamic apertures
- Historically no beam gap synchronized to extraction kickers -- systematic 2% beam loss at extraction septum
- Longitudinal instabilities after transition at high current
- RF capture inefficiencies
- Space charge blowup ?
- ??
Toward Control and Solution to Problem

– Continued aperture improvements
  • magnet moves to remove aperture constraints
  • study increased RF cavity aperture
  • improved orbit control
    – orbit adjustment program
    – ramped correctors w/ beam position feedback
    – improved main magnet control

– Create and synch beam gap with extraction kicker
  • presently able to create notch at 400 MeV after injection with short kicker
  • investigating laser neutralization gap creation
  • synchronization to circulating Main Injector beam is complicated and narrowly constrained by beam dynamics
Toward Control and Solution to Problem

- Improved longitudinal dampers
- Scraper/collimator
  - control loss of particles that cannot be retained
  - design is commencing based on new Booster model
- New BLM transducer and data acquisition system
  - ability to quantitatively see and record when and where beam losses occur under complicated operating scenarios is essential to facilitate and measure progress