Optimization of the Booster Notch System

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APT Talk

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Booster Beam Notching

- Purpose of Notching
- Background
- Implementation
- Performance
- Modifications
- Current Operations
- Future Plans
Purpose of Notching

• Notching is planned removal of selected proton bunches to facilitate a gap in the beam at extraction time.

• This gap allows the Booster extraction kicker magnetic fields to reach full value to allow extraction of the remaining bunches. Only 2 bunches need be removed but due to bucket jitter in the transfer to MI/Recycler, a third is removed as well. Thus 81 bunches are transferred.

• Without the gap or “notch” in the beam, the extraction kickers would displace these bunches in a non-controlled fashion causing losses in the extraction region at 8GeV.

• In the past “notching” was less critical due to lower beam intensities and lower beam duty cycles. Losses were tolerable.
Notching Pre-Shutdown 2012/13

- A 3 bucket gap is created using kickers located at Long 5 and Long 12
- Notcher – A High Voltage (55kV) Kicker at Long 5
  - Noker - Lower Voltage Kicker (20-40 kV) at Long 12
    - Used to clean out remnant notched beam in buckets at ~700 MeV due to Cogging operations.
- Beam is kicked vertically into gradient magnet dipoles at L5 and L12. Some notched beam reaches the collimator region at Long 6 and beam pipe mask at Long 13. This worked and was best option at the time.
- Non-cogged notched cycles occurred at ~400 MeV.
- Cogged notch cycles occurred at ~700 MeV to allow for cogging synchronization process.
Residual dose profiles, vertical cross section (30 days irradiation/1 day cooling, mSv/hr).

**Vertical notcher @ L5**

**Proposed Horizontal notcher @ L5**
Option 3 was chosen for horizontal notching

Conclusions

1. One vertical notcher removes 87% of 3-bunch intensity, with 75% loss at pole tip of Booster magnets, 11% at collimator, and 0.5% on the rest part of the ring.

2. We propose to improve the notching efficiency and beam loss in the accelerator by rotating existing notcher and pinger by 90 degree, and increasing the aperture of Short-05 straight section from R57mm to R87mm. Using two horizontal notchers with shift of their pulses by +/- (4-7)nsec, is possible to remove 95% of 3-bunch intensity, with 93% loss at collimator and 2.6% on the rest part of the ring at 400 MeV.

3. Using three horizontal notchers at Long-12, is possible to remove 98% at 400MeV and 94% at 700 MeV of 3-bunch intensity to the beam dump located at Long-13 straight section with increased aperture of Short-12 section to R87mm by aperture displacement to dX=20mm.
Longitudinal distribution of 3 removing (red), circulating (green) and survival at notching (blue) bunches, and long (1.08m) and short (0.54m) notchers waveform at Long-13, and 1.08-m notcher waveform for Long-05 straight section.
Long-13: Loss Simulations For Horz. Notching

Side view

Top view
Implementation

- Simulations for horizontal notching concluded that 3 kickers could be utilized to send beam between the 400-700 MeV energy range to a dedicated absorber.
- An ideal location would be L13 as this had the available space. L12 also had space for the notching magnets.
- Modifications were made to the standard S12 corrector spool to allow additional aperture.
Notching Pulser System using 2 CX2610 pulsed thyratrons
L12 Straight section

6 half meter long pulsed magnetic kickers
New Pulser system has faster rise/fill time
Long 13

**Notched beam absorber**

Used for clean-up of vertical notched beam L13

Dedicated L13 Notch Absorber
Long 13

Former vertical notch clean-up area

Long 13 Notched beam Absorber downstream view

Beam direction
Notched Beam
Absorber Liner with 12” insert

Circulating beam

Notched beam
Bunch length: 4.5 nsec @ 1 sigma

$dp/p$: 0.0011 @ 3 sigma

Notcher voltage: 34 kV @ peak
Booster_aperture_L12
H_up
H_down
kicked beam (32kV)
circulating beam
circulating beam
circulating beam
kicked
circulating
H_position \[m\]
L_distance \[m\]

Aperture L12-L13

Horz. Radial Inside
Horz. Radial outside
kicked beam (32kV)
kicked beam (32kV)
kicked beam (32kV)
circulating beam
circulating beam
circulating beam
circulating beam
kicked
circulating
H_emittance: 16 pi mm mrad
V_emittance: 14 pi mm mrad
Size: 5 sigma

Absorber edge: 19.93 mm (set to 590 mils) Face: 51.69 mm
Second Liner modification  Insert section
Areas of concern, in red boxes, due to notch losses. They are managed but would prefer them lower.

Notch Region
Top view of magnets

Notching kickers

Diagram continued below
Short 12 Booster corrector with modified spool for Aperture
L12 Mini-straight
L13 Upstream notched beam Absorber

Beam Direction
L13 downstream absorber mask
400 MeV Notched beam Absorber Retracted

Normalized Booster BLMs

References: 2016-09-12 11:54:38
400 MeV Notched beam
Absorber in operational position
Notching turned On and Off

Extraction loss monitor

Beam Charge

Notching on

Notching off
Notch formed @ 32kV

1st turn  2nd turn

Notch formed @ 39kV
Notch depth relative to extraction losses

31kV kick

35kV kick
Fast loss Signals downstream of 5-3 and collimator 6b

PMT signals

31kV kick

Reduced multi-turn losses

35kV kick
Losses at notch formation seen at other locations
Notch enabled and disabled for comparison
Notched loss difference when beam is aligned well
Transition from Notching at L5 (vert.) to L12(horz.)

Horizontal Notching L12/L13

Vertical notching L6/L13

Installed and removed 1st liner insert

Installed 2nd liner insert

shutdown

shutdown

shutdown

shutdown
Current Notching Status

• The gap is 3 bunches wide at 8GeV.
• We are able to maintain a 2 bunch gap now with cogging jitter compensation. Down stream machines currently cannot utilize smaller gap. So we continue to notch 3 bunches.
• We continue to try and optimize our orbits and tweak notch time relative to beam recapture time.
• Continuing to reduce multi-turn loss effect via studies.
• Working towards improved diagnostic with fast loss detector implementation for routine tuning of notch loss.
• Will place additional shielding at upstream end of absorber.
• Will review improvements to downstream absorber mask.
• Look at ways to improve rise time of extraction kickers.
Conclusion

• Notching is currently working better than before.
• This allows us to run greater beam throughput and maintain/reduce beam loss away from critical components.
• We need to further reduce losses in critical areas with another iteration of improvements to the current system.
• We gain more tuning capability with improved diagnostics.
• We have lowered beam losses by utilizing magnetic cogging to allow for all beam cycles to be notch at 400MeV rather than many at 700MeV.
• We will gain further margin with laser notching in the Linac.
• Improved injection orbit management and better models will further determine areas of improvement.