**Booster Notching Review**

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**Introduction**

The current notching scheme in the Booster will not be adequate for the future 15 Hz operation due to high radiation losses.

A new notching scheme has been proposed using 3 long kickers located at Long 12 that kick the beam horizontally into a new absorber at Long 13.

We were asked to review the design and feasibility of the new notching system and comment on potential improvements.

**Notching Kickers**

**Findings**

Three Long (1.08 m long) kicker magnets are going to be used for the new notching scheme. Two of those kickers are already in the Booster and a third is to be built with existing parts. In phase 2 the 3 Long kicker magnets are to be converted to 6 Short style kicker magnets driven by a faster thyratron in order to create a cleaner notch.

The notching efficiency at 400 MeV (notching energy for non-cogged cycles) is about 98% (62 Gauss field, 46 KV) for both Long and Short kickers. At 700 MeV (notching energy for cogged cycles) the notching efficiency drops to 92% and 94% for Long and Short kickers respectively (72.5 Gauss field, 54 kV). These efficiencies can increase to 98-99% by running the kickers at a higher field (80 Gauss field, 60 KV).

**Comments**

All simulations for notching efficiency are using kicker wave forms of the load current not taking into account the kicker drift time.

Finite kicker fill times combined with magnet drift time will create conflicts between removing all of the unwanted 3 bunches versus rattling the adjacent bunches. Careful measurements of the time profile

of beam deflections will allow one to fully characterize the kicker system properties.

8 Gev losses due to beam which is not removed at 400 or 700 MeV (or which is disturbed and had high transverse emittance) can create 11 to 20 times as much radioactivity. Further, it can be deposited at

locations which are less suitably designed to contain it. Thus, in tuning the system, one will need to systematically evaluate the impact of higher kicks which remove more of the targeted bunches but may increase losses at 8 GeV within the Booster, in the 8 GeV Line or in the Main Injector.

Running the notching kickers at higher fields (voltages) in order to increase the efficiency will shorten the lifetime of the kicker cables. This lifetime should be considered to understand whether or not it will create an operational issue.

**Recommendations**

Use the bunch by bunch transverse damper diagnostics to map the notching kicker waveform.

**Beam Absorber**

**Findings**

The design of the beam absorber is in advanced stage. It consists of a vacuum liner surrounded with steel absorber blocks and concrete. There is a driving system providing a total of 1.0’’ motion of the moving block. Two polyethylene maskes are mounted around the vacuum liner in the upstream and downstream ends of the absorber. The beam power in the absorber is at most 300 watts (assuming notching of all Booster cycles at 700 MeV).

**Comments**

Thermal Considerations:

The thermal model of the absorber had not been developed sufficiently to identify an escape for the heat. At only 300 watts, we can be fairly sure that some combination of conduction and convection will prevent the mass from reaching the temperatures shown in the calculations. The calculation need only set an upper limit to the temperature. A simple boundary condition would be to add conduction down the beam pipe, ignoring other heat loss and demonstrate that to be sufficient.

The radiation concerns for this system include ALARA for persons passing the area, sump water activation by activation of materials outside of the tunnel, and beam-on radiation in the Booster gallery.

This should be a 'no-maintenance' installation so hands-on maintenance considerations apply only to upstream or downstream areas. Unlike the MI collimation system where concern for decay muons drove a design with minimal gaps in the region of high particle concentration, the sump water issue is dominated by neutrons. The beam-on neutron problem is dominated by low energy neutrons which can propagate up the cable penetrations. The proposed design has more gaps in the shower region but this is not expected to provide significant increased radiation.

1. Wall Side Situation:

The calculation presented in the review reported that additional shielding was needed between the initially proposed absorber and the inside tunnel wall. The proposed addition of steel plus sand bags is certainly not suitable. As we have seen in the Main Injector, the sand bags will fail in a high radiation environment. An alternative shielding will be required.

1. Aisle Side Considerations

 The proposed absorber surrounds the new beam pipe assembly with thick iron followed by concrete. This appears to be a suitable solution for protection from neutrons. The possible use of marble to further reduce the personnel exposure may be valuable. Concrete will be activated. We have found that the longer half life isotopes are more attenuated by marble than are the short half life ones. This might or might not be true for the concrete.

1. Beam-on (above ground) Considerations

 In discussions with Mokhov and Tropin, the issues of slow neutron attenuation appear to be worth further consideration. Making sure all iron near the inner wall has a layer of concrete or polyethylene will significantly impact the beam-on radiation issues. It appears that blocks or sheets of polyethylene placed on the top of the other shielding (inside top corner) will be a good option. Mokhov reports that some polyethylene may be available from NTF but more significantly, lots of polyethylene can be 'repurposed' from the D0 detector installation where it was used extensively.

Mask Considerations:

The existing installation includes some 'masks' at L13. Optimizing of these will reduce the personnel exposure. One mask should be as near as convenient to the absorber with the other as far downstream as is convenient to protect the corrector package from small angle out scattered beam.

a) The upstream few inches (perhaps 4" or so) could be circular near the beam pipe to further absorb particles at small angles.

b) Surrounding them with marble is of significant advantage to achieve reduced residual radiation. For the MI Marble masks, the upstream face was covered. For this size, the same benefit can be obtained by extending the marble upstream of the hot face. The design alternatives should be presented to the engineer.

To document the successes of your shielding system, the use of Al Tag activation can be quite effective. A bit of planning will allow one to place tags at locations where MARS results are not unduly sensitive to placement details. One can then use the ratio of exposure at Al Tag locations vs. exposure outside the tunnel to document the sump water exposure. See Beams-doc-3989.

**Recommendations**

1. Consider solutions for additional shielding on the wall side of the absorber that do not include sand bags. A direct comparison of the proposed additional steel vs. a comparable amount of concrete should be examined. At this point we may expect that the prompt radiation is dominated by moderate

energy neutrons. To make a more complete containment inside the tunnel, one could fabricate shielding blocks special-made for this location. Vendors which make concrete shaped to specification are available locally. Consideration for 'heavy' concrete vs. the standard mix would be based on MARS simulations. Mokhov has a contact name at Argonne who regularly obtains specially shaped heavy concrete shieding.

2.Consider aisle side alternative designs that include marble.