THE CONCEPT DESIGN OF A TRANSFER LINE FROM THE RECYCLER TO THE MAIN INJECTOR FOR THE FERMILAB NOVA PROJECT*

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Abstract

Upon the termination of the Fermilab Collider program, the current Recycler anti-proton storage ring will be converted to a proton pre-injector for the Main Injector synchrotron. This is scheduled to increase the beam power for the 120 GeV Neutrino program to upwards of 700KW. Due to momentum aperture requirements, a Recycler to Main Injector transport line will be constructed wholly within a horizontal dispersion free region in the 30 straight section. The concept design will be presented in this paper.

INTRODUCTION

The delivery of high intensity proton beam for neutrino experiments is a core element of the Fermilab physics program for the next decade and beyond[1][2]. The scope of the accelerator upgrade portion of the NOVA project is to increase the beam power of the 120 GeV beam from the Main Injector onto the NuMI target to 700 kW from the present level of 192 kW. The upgrade will build on the "Proton Plan" that aims at increasing the 120 GeV beam power to 320 kW. The required increase in the proton throughput of the Booster is planned to be achieved entirely as part of the "Proton Plan". The three times increase of the proton throughput of the Main Injector (MI) will be achieved by using the Recycler Ring (RR) for slip-stacking 12 proton batches from the Booster and reducing the MI cycle time to 1.333 s. The existing extraction line has the problem for slip-stacked beam from RR to MI with the aperture limitation, since the RR lambertson is located in a very large dispersion region (D=1.97m at RR214). Therefore, a new transfer line needs to be designed to extract beam from RR to MI. On the other hand, RR30 straight section right now contain the symmetric electron-cooling insert between 305 and 307, we would like to re-build FODO lattice as initial Recycler design, since Electron-cooling devices will be taken out for future use.

RR 30 STRAIGHT SECTION

MI-30 straight section is a "D-D 8 half-cell" straight section which starts at 301 and ends at 309, both horizontally defocusing locations. The MI lattice is a periodic FODO in the region. The Recycler lattice contains the symmetric electron cooling insert between 305 and 307 with remainder of the Recycler straight section is roughly a FODO section, but not periodic. The Recycler straight section between Q301 and 309 will be replaced with the FODO lattice. Figure 1a and b give the beta functions of two types of the lattice.

Notice that there are 3 quads in each D-D half-cell in SS30-FODO section due to permanent magnet quad strength limitations. To match the FODO straight section into the ring and keep the current tunes, the lattice functions reach a peak value of 80 m. Utilization of a 3" round beam pipe through this region gives an aperture to beam size ratio of 14 σ_{95}(95% of beam size).

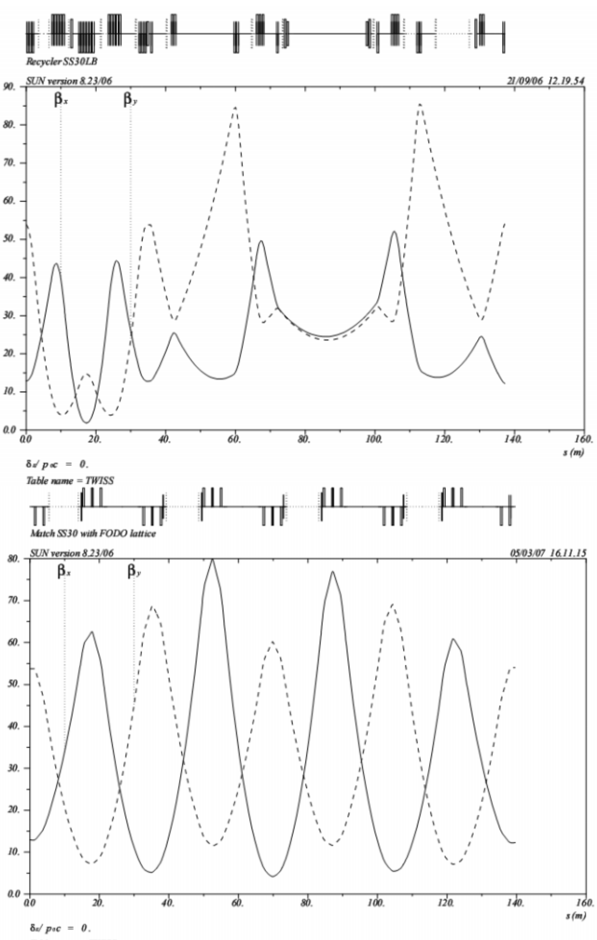

Fig.1 Beta-functions of existing SS30 for E-cool purposes (upper) and SS30-FODO with 3 quads in a half cell (lower).

EXTRACTION LINE

The extraction line starts with an extraction kicker located at RR 230, approximately 90^o upstream of a vertical lambertson. The lambertson bends the extracted beam down. Vertical dipoles, located approximately 90^o and 180^o down stream, bend the beam up and down respectively. A final vertical bend by MI style lambertson(ILA) located at MI306 places the injected

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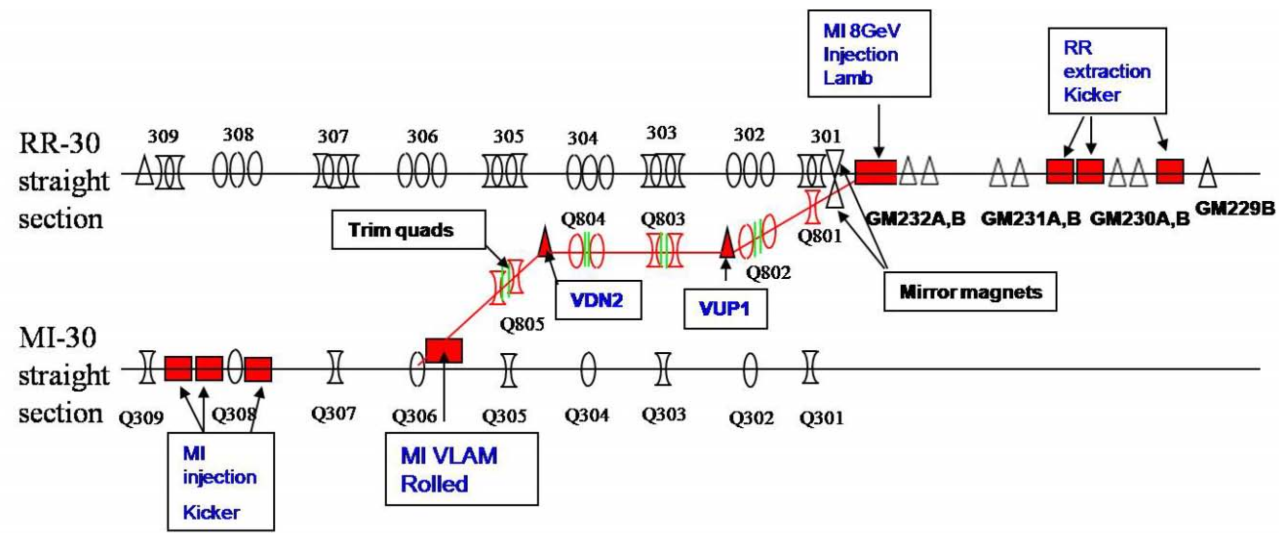

Fig. 2 Cartoon of extraction line, including RR and MI 30 straight section.

beam onto the MI vertical closed orbit. The focusing properties follow those of the MI FODO structure which eliminates the need for a special lattice matching sector in the transport line. The MI injection kicker is then located 90^{o} downstream of the lambertson at MI308, to place the injected beam on the MI horizontal closed orbit. Electromagnet quad trims at each permanent magnet pair are included for fine tuning of matching constraints. Correction dipoles are included at each location for orbit control. Figure 4 shows the lattice match for the beam line with zero trim quad settings.

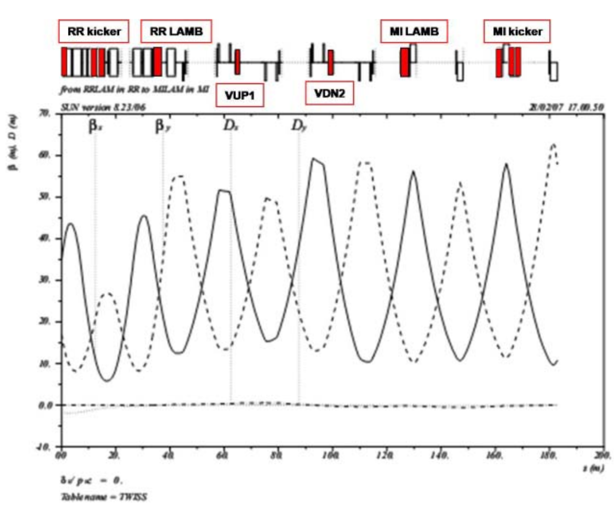

Fig. 3 β- and dispersion functions of the extraction line.

RECYCLER EXTRACTION KICKER

Figure 4 shows the trajectory of circulating beam with a closed orbit 3-bump, creating +25mm offset at the entrance of the Lambertson at 232 , and the trajectory of extracted beam with the kicker located at 230, kicking the beam to -25mm at the entrance of the Lambertson. The kicker strength required is 504 G-m.

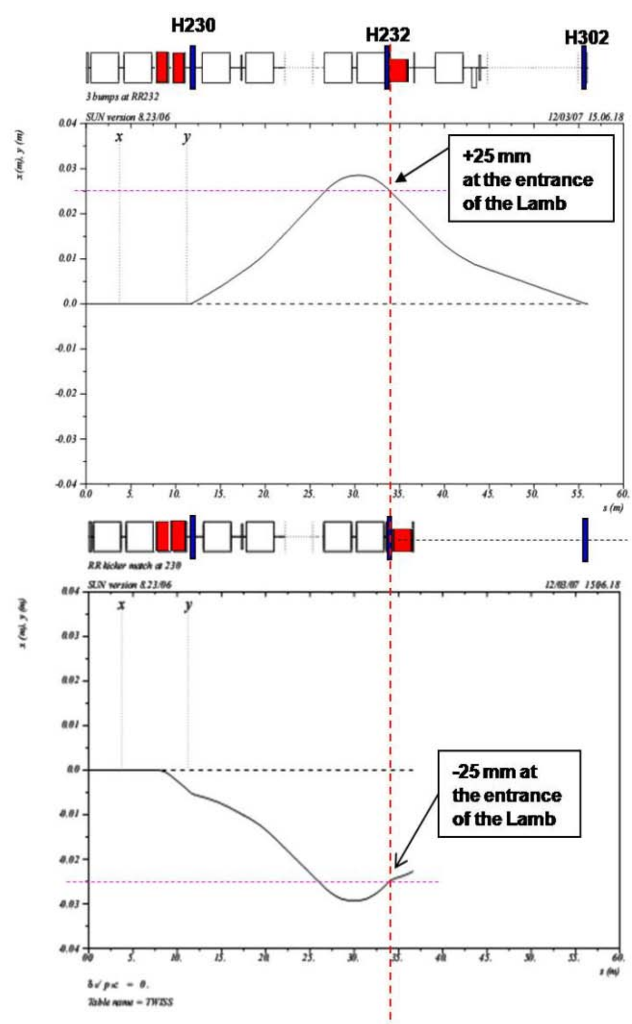

Fig. 4 Trajectories of circulating and extracted beam. The red blocks represent kicker modules. The blue blocks are 3 correctors.

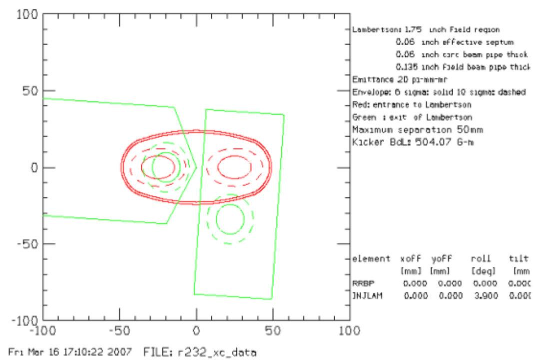

Fig. 5 The aperture at RR extraction Lambertson.

Figure 5 shows the apertures at the RR extraction Lambertson. Here the emittance of the beam is 20 π-mm-mrad. The solid and dashed lines represent a 6σ and 10σ beam envelope. The red envelopes are at the entrance of the lambertson while the green represent the extracted beam envelope at the exit of the lambertson.

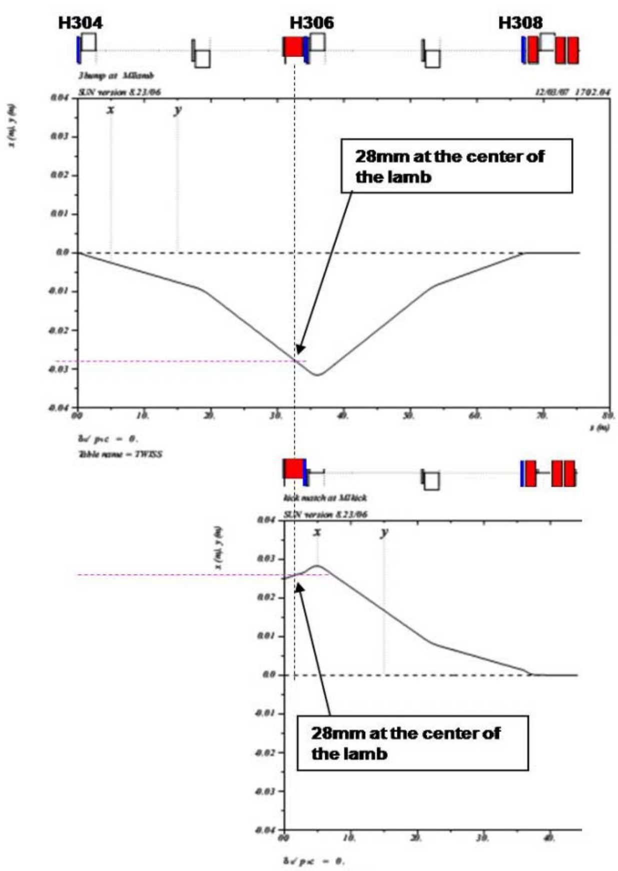

Fig. 6 The trajectories of the circulating beam (upper) and injected beam in Main Injector (down). The red blocks represent kicker modules. The blue blocks are 3 correctors.

MAIN INJECTOR INJECTION KICKER

Figure 6 shows the trajectory of circulating beam with a closed orbit 3-bump, creating +28mm offset at the center of the Lambertson at 306 in MI, and the trajectory of injected beam with the kicker located at 308, kicking the beam into MI horizontal closed orbit. The required kicker strength is 368 G-m.

Figure 7 shows the apertures at the MI injection Lambertson. Here the emittance of the beam is 20 π-mm-mrad. The solid and dashed lines represent a 6σ and 10σ beam envelope. The red envelopes are at the entrance of the lambertson while the green represent the extracted beam envelope at the exit of the lambertson.

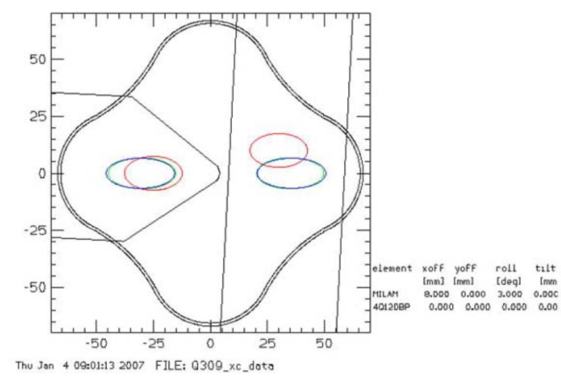

Fig. 7 The aperture at the MI injection Lambertson.

CONCLUSION

The extraction line is designed in a horizontal dispersion free region. The pair of down bends and up bends, separated by 180^{o}, kills the vertical dispersion naturally. Permanent magnets are used for all quadrupoles. Electro-magnets are used only for vertical bends and dipole and quad corrections. The design is consistent with planned installation of collimating system in Main Injector. All the apertures have been checked and found to be at least larger than 10σ. 3D models have been constructed for RR/MI-30 and extraction line to make sure there are no magnet interferences with the other beam lines.

REFERENCES

[1] D. McGinnis, “A 2 Megawatt Multi-Stage Proton Accumulator”, Fermilab Beam document 1782-V7.

[2] Conceptual design Report, Proton Plan 2, Navermber 9, 2006 (updated 1/31/2007). http://www-nova.fnal.gov/nova_cd2_review/anu_cdr_1375_v1.pdf.