RECYCLER LATTICE FOR PROJECT X AT FERMILAB *

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Abstract

Projext X is an intense proton source that provides beam for various physics programs. The source consists of an 8 GeV H- superconducting linac that injects into the Fermilab Recycler where H- are converted to protons. Protons are provided to the Main Injector and accelerated to desired energy (in the range 60 - 120 GeV) or extracted from the Recycler for the 8 GeV program. A long drift space is needed to accommodate the injection chicane with stripping foils. The Recycler is a fixed 8 GeV kinetic energy storage ring using permanent gradient magnets. A phase trombone straight section is used to control the tunes. In this paper, the existing FODO lattice in the RR10 straight section being converted into doublet will be described. Due to this change, the phase trombone straight section has to be modified to bring the tunes to the nominal working point. A toy lattice of recycler ring is designed to simulate the end-shim effects of each permanent gradient magnet to add the flexibility to handle the tune shift to the lattice during the operation of 1.6E14 with KV distribution of the proton beam to give ~0.05 of space charge tune shift. The comparison or the combinations of the two modification ways for the Recycler ring lattice will be presented also in this paper.

INTRODUCTION

Project X [1] is an intense proton source that provides beam for various physics programs. The source consists of an 8 GeV H- superconducting linac that injects into the Recycler where H- are converted to protons. Protons are provided to the Main Injector and accelerated to desired energy or extracted from the Recycler for the 8 GeV program. The Recycler ring (shown in Fig. 1) is a fixed 8 GeV kinetic energy storage ring using permanent gradient magnets. RR10 is the straight section for placing the injection system and RR60 is a phase trombone straight section used to control the tunes.

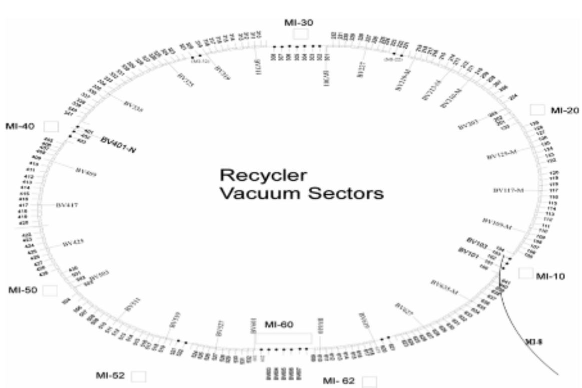

Fig. 1: Outline of the Recycler ring

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Currently, In the recycler lattice for Project Run II, RR30 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, shown in Fig. 2. This section will be replaced by a FODO lattice for Project NOvA [2], shown in Fig. 3. Notice that there are 3 quads in each D-D half-cell in RR30 due to permanent magnet quad strength limitations. To match the FODO straight section into the ring and keep the current tunes (25.425,24.415) , the lattice functions reach a peak value of 80 m.

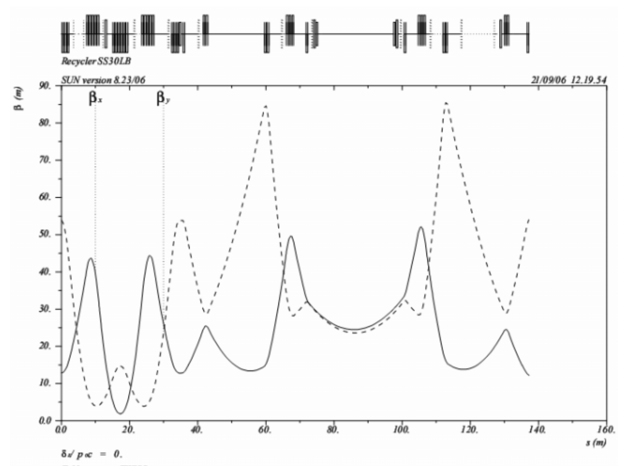

Fig.2: RR30 in the Recycler lattice for Project Run II

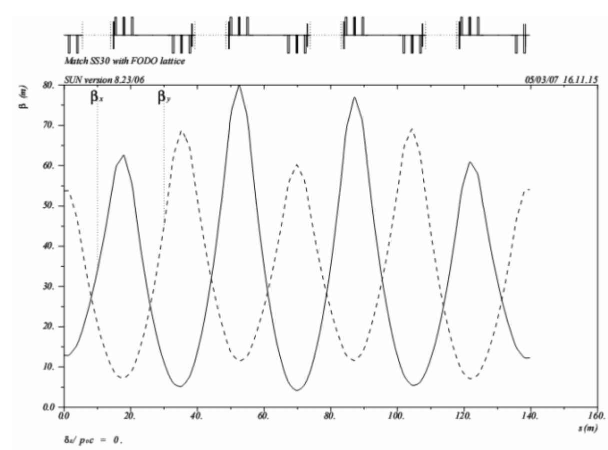

Fig.3: RR30 in the Recycler lattice for Project NOvA

The Recycler lattice for Project X will be based on The lattice for NOvA. Keep RR30 straight section as FODO cell but would lower the beta functions as the rest of the ring. We will also keep using extraction line from the Recycler to the Main Injector.

RR10 STRAIGHT SECTION OF THE RECYCELER LATTICE FOR PROJECT X

The inject system for convert H^- to proton in Recycler is a multi turn stripping system which will be placed in RR10 straight section. Fig. 4 illustrates the injection Chicane with stripping foils

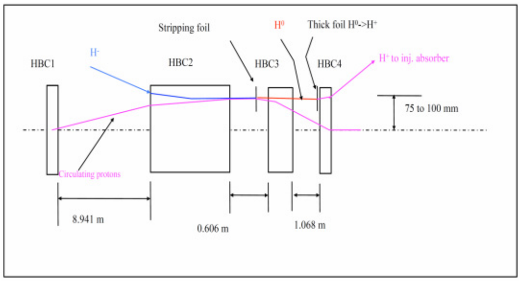

Fig.5: Injection system in RR10 straight section

To accommodate this, a 21.5 m long drift space is designed by converting the existing FODO lattice in RR10 straight section into a doublet, shown in Fig. 6.1 Meanwhile, constrain the β_x ,β_y< 55 m in RR30, the Recycler lattice become as shown in Fig.6.2. The tunes now become (25.445, 24.134).

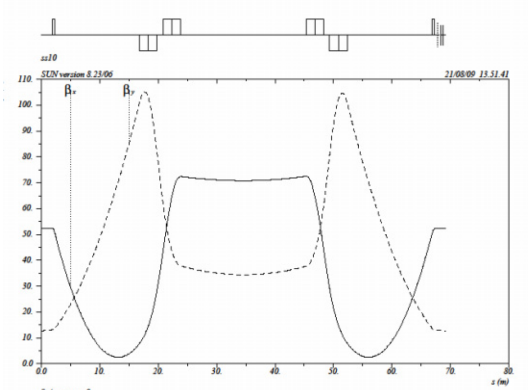

Fig. 6.1: Doublet in RR10 section

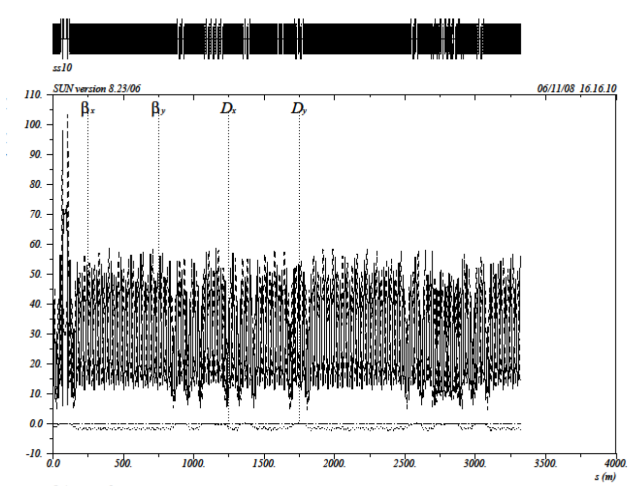

Fig. 6.2: Recycler lattice with a doublet in RR10 and RR30 constrained the β_x ,β_y< 55 m

SOLUTIONS TO THE NOMINAL TUNES

RR 60 straight section is a phase trombone for Recycler tune control. It contains 32 permanent quads in 4 D-D FODO cells, and 36 trim quads in 9 families which are installed in the drift space of FODO cells, the basic settings of their currents are 0. Fig. 7 illustrates the two types of the quads.

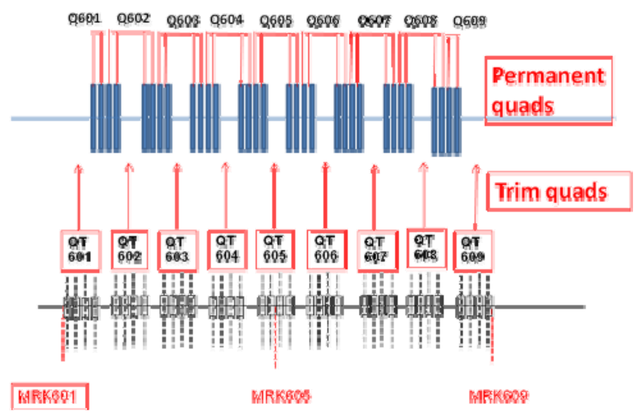

Fig. 7: Permanent quads and trim quads in RR60 phase trombone section

The First Solution

We kept the rest of the Recycler ring unchanged, but only varied the strengths of permanent quads in RR60 phase trombone straight section with the constrains:

- Keep $\alpha_{x,y}$, $\beta_{x,y}$ at two ends of the phase trombone RR60 unchange
- β_x,β_y<55 m
- Phase advance set to compensate the tune difference from the nominal tunes

We obtained (from MAD fitting):

$$\begin{cases} Q_x = 25.329 \\ Q_y = 24.350 \end{cases}$$

when

$$\begin{cases} k_1 Q60_F = 0.05404106 \\ k_1 Q60_D = -0.06359425 \end{cases}$$

Then we used trim quads to re-adjust base tunes. We obtained the tunes Q_x=25.425,Q_y=24.415 when

$$\begin{cases} QT601\_I = -0.6149 \\ QT602\_I = 0.7229 \\ QT603\_I = -1.0923 \\ QT604\_I = 2.9553 \\ QT605\_I = -1.8319 \\ QT606\_I = 2.8896 \\ QT607\_I = -1.2121 \\ QT608\_I = 0.7283 \\ QT609\_I = -0.4635 \end{cases}$$

by a Mathematica program[3], which will be used in an application program for on-line tuning.

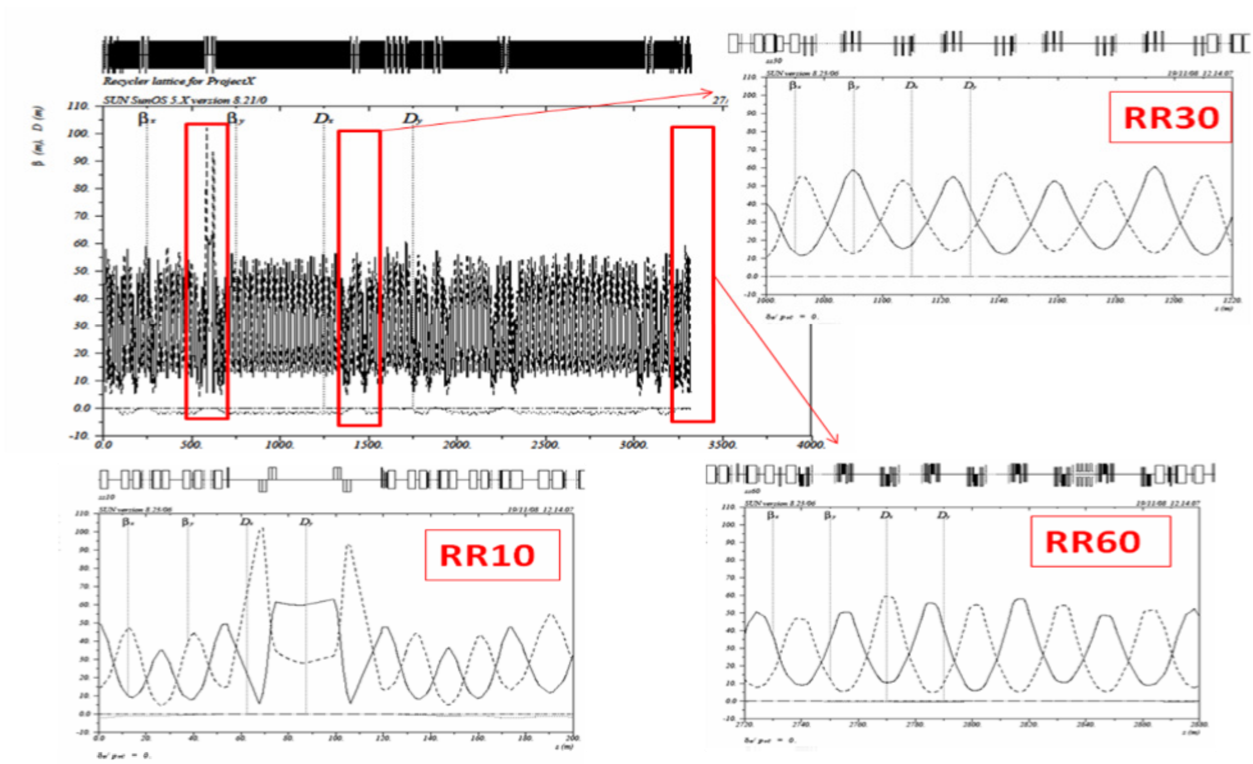

Fig. 8: Recycler lattice for Project X. Only the trombone section was modified.

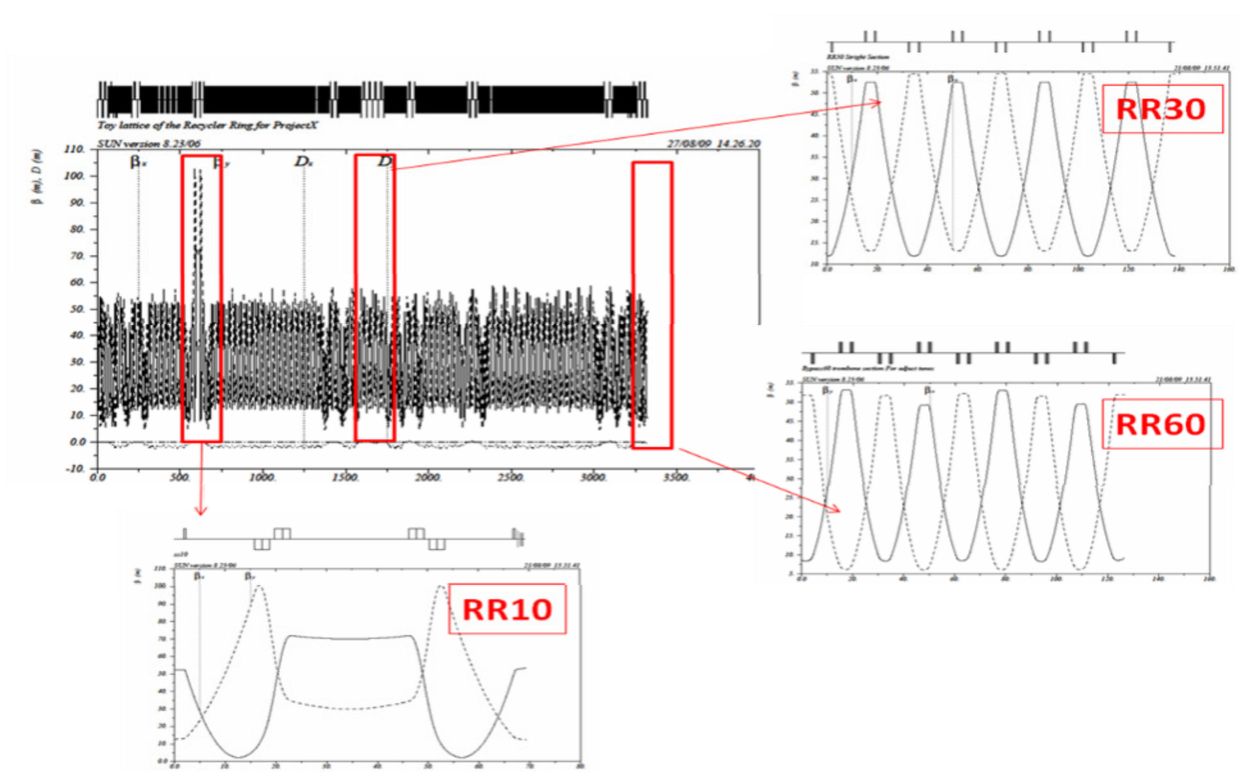

Fig. 9: Toy Recycler lattice. End-shim of each permanent gradient magnet in arc cell was tweaked so that the arc cell phase advance was slightly changed.

Notice that the currents of QT604 and QT606 are around 3 Amps. Actually the trim quads current could be changed up to 5 Amps. But the larger the currents, the larger the non-linear contribution to the operation program. With this solution, the recycler lattice for Project X shown in Fig. 8.

The Second Solution

To add the flexibility to handle the space charge tune shift (~0.05) due to the beam of 1.6e14 with KV distribution, a toy lattice of the Recycler ring was built to simulate the end-shim effects of each permanent gradient magnet. It was found that the amount of the end-shim field tweaked is limited in order to eliminate the large beta-wave in the lattice. We then varied the permanent quads in RR60 again to obtain the nominal tunes (25.425, 24.415) with zero the trim quads current.

In the toy lattice:

- The phase advances of the arc cell were slightly changed from $\mu_x = 85.39^o$, $\mu_y = 79.22^o$ to $\mu_x = 84.45^o$, $\mu_y = 79.95^o$
- The phase advances of the normal straight section cell keep the same $\mu_x = 86.51^o$, $\mu_y = 80.34^o$
- The phase advances of the dispersion cell were changed slightly to $\mu_x = 87.85^o$, $\mu_y = 89.83^o$ to fit from arc cell to straight section cell.
- The phase advances of the RR60 trombone section straight section now are : $\mu_x = 97.53^o$, $\mu_y = 115.29^o$

This means:

- The amount of the end-shim tweaked is about 1% of the body quads field in horizontal and 0.5% in vertical planes.
- The amount of the strength of the permanent quads in RR60 is increased about 4% in horizontal and 13% in vertical planes.
- The currents of the trim quads in RR60 are 0 .

The toy lattice of the Recycler ring for Project X is shown in Fig. 9.

Apparently the second solution is more flexible to handle the space charge tune shift, but it needs a lot of work to adjust end-shim contributions. Technically it is doable.

CONCLUSION

Several considerations have been taken in modifying Recycler lattice for Project X. The Recycler lattice is manageable for Project X with some uncertainties on a. Beta functions on injection point(stripping foils) b. Nominal tunes considering the tune shift due to space charge effect. Toy lattice will be used do beam dynamics studies with space charge effects for looking for best nominal tunes.

REFERENCES

[1] Projext X ICD-1 . http://projectx.fnal.gov/index.html

[2] Meiqin Xiao, “RR-30 straight section/Extraction Line Lattice Design”. http://nova-docdb.fnal.gov:8080/cgi-bin/ShowDocument?docid=3099

[3] Meiqin Xiao, “Measurement and corrections of the Recycler Lattice at Fermilab”. Proceeding of HB2008, August 25-29, 2008, Nashville