REMATCHING AGS BOOSTER SYNCHROTRON INJECTION LATTICE FOR SMALLER TRANSVERSE BEAM EMITTANCES*

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Abstract

The polarized proton beam is injected into the BNL AGS booster via the charge-exchange (H- to H+) scheme. The emittance growth due to scattering at the stripping foil is proportional to the beta functions at the foil. It was demonstrated that the current scheme of reducing the beta functions at the stripping foil preserves the emittance better; however, the betatron tunes are above but very close to half integer. Due to concern of space charge and half integer resonance in general, options of lattice designs aimed towards reducing the beta functions at the stripping foil with tunes at more favorable places are explored.

INTRODUCTION

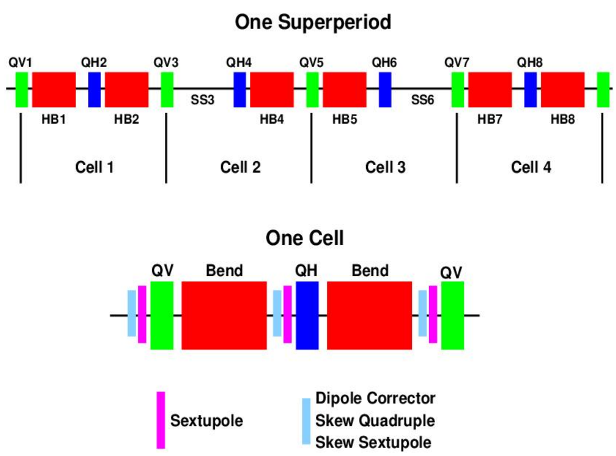

Figure 1: The magnetic elements in one super-period in the Booster ring. The ring consists of 6 super-periods. Beam direction is from left to right.

The Booster [1, 2], which serves as injector into the AGS, is a circular machine with a circumference of about 200 m, one fourth that of the AGS. It receives and accelerates polarized protons from the 200 MeV Linac and various other ions from the Electron Beam Ion Source (EBIS) and the Tandem van de Graaff. The Booster lattice consists of 24 separated-function FODO cells grouped into six superperiods labeled A through F. The magnetic elements in a superperiod are shown in Fig. 1. In each superperiod there are two missing dipoles which provide the necessary space for injection, extraction, RF acceleration, beam dumping, and instrumentation. H-minus ions from Linac are injected into Booster through the backleg of the C5 dipole magnet. A 100 to 200 microgram per cm^2 carbon foil located just upstream of the C6 quadrupole strips away the H-minus ion electrons.

The lattice quadrupoles have a five-turn main winding, a single-turn tune winding (for adjusting the machine tunes), and a two-turn auxiliary winding for half-interger resonance correction [3]. The nominal Courant-Snyder parameters of the lattice are shown in Fig. 2.

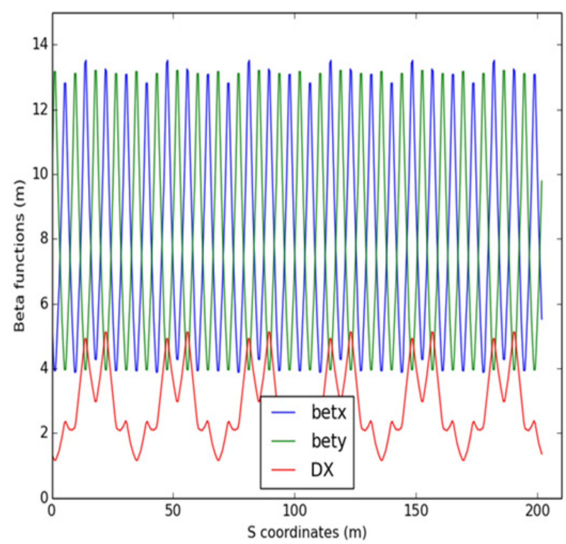

Figure 2: The Courant-Snyder parameters of the Booster ring, the horizontal beta function in blue, the vertical beta function in green and the horizontal dispersion in red.

Multiple scattering of circulating beam passing through the H-minus stripping foil is a significant contributor to emittance growth during the multiturn injection of Linac beam. Several ways of reducing the growth have been explored and are documented in [4]. As noted there, the growth in the rms emittance of a group of protons passing n times through the foil is given by [5, 6]

$$\Delta\epsilon_{rms} = \frac{1}{2} n\beta(s)\varphi_{rms}^2 \qquad (1)$$

Where β is the lattice beta at the foil and φ_{rms} is the rms angular kick received by the group in a single pass through the foil. In [6] it is shown, with the help of the code TRIM [7], that φ_{rms} = 0.0243 and 0.0344 milliradians for 200 MeV protons passing through 100 and 200 microgram per cm^2 carbon foils, respectively. Foils thinner than 100 micrograms per cm^2 are fragile, and the

*Work performed under Contract No. DE-AC02-98CH1-886 with the auspices of the DOE of United States.
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ISBN 978-3-95450-182-3

fraction of neutral H atoms or unstripped H-minus ions emerging from them is high enough to cause concern for machine components downstream. This leaves reducing the factor β in (1) as the primary means of reducing emittance growth.

The current scheme for reducing β-functions in both planes at the stripping foil was documented in [4]. The desired reduction is achieved by bringing the betatron tunes close to and above 4.5 while exciting the half-integer resonance correction windings to distort the horizontal and vertical beta functions. The emittance growth in the horizontal plane is found to be significantly reduced, but little reduction is seen in the vertical plane. One disadvantage of the scheme is, of course, the proximity of the half-integer resonance. In particular, having the set tunes slightly above 4.5 is problematic as the incoherent space-charge tune shift increases with intensity. The focus of the present report is to explore alternative ways of reducing the beta functions at the H-minus striping foil without having to move the tunes close to the half-integer.

ALTERNATIVE SOLUTION WITH HIGHER BETATRON TUNES

In the simulations performed using MAD-X, the excitations of quadrupoles close to the foil are chosen as variables. Various numbers and excitation of quadrupoles were tested.

In the first scenario of simulation, additional power supplies were added on the main windings of selected quadrupoles. The goal of the simulation was to reduce the β-functions to (6, 3) m at the stripping foil with the betatron tunes held at 4.7/4.75. The required currents from the additional power supplies were found to be ~200 A. The required voltage on the additional power supplies for the fast ramping of Booster magnets is high as well as the cost [8].

In the second scenario, additional power supplies were put on the tune windings of selected quadrupoles. The half integer power supplies are employed in the optimization as well with the current limit (-20, 20A) [8]. With the same goal as in previous case, the required currents from the additional power supplies are ~400 A. This option is not practical because the required current on the tune windings are too high.

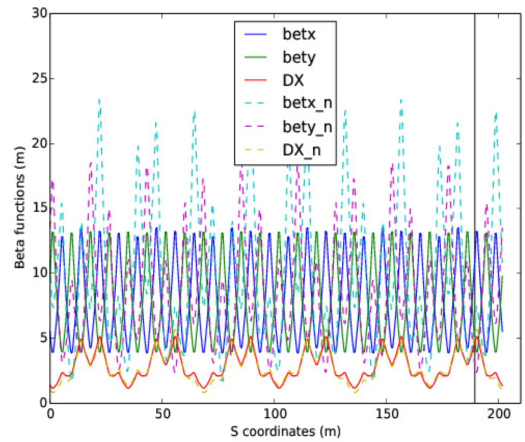

Figure 3: The distorted Courant-Snyder parameters in the Booster are shown in dashed lines, and the nominal ones are shown in the solid lines. The vertical black line is at the stripping foil.

In the third scenario, only the half integer resonance strings were employed as variables without previously mentioned current limits. The tune strings were used to compensate the resulting tune changes. The tunes were held at 4.7/4.75. The required currents for the resonance strings are: qvstr1 = 29.5; qvstr2 = -73.0; qhstr1 = -62.1; qhstr2 = -74.6. The achieved beta functions at the foil are (6, 3) m as shown in Fig. 3. The power supply upgrade needed for this scheme is the most practical and is under consideration for implementation.

ALTERNATIVE SOLUTION WITH BETATRON TUNES BELOW HALF INTEGER

We also tried to design a lattice with tunes below half integer for proton injection so that the betatron tunes would be shifted away from half integer stopband due to space charge. The polarized proton beam is extracted at Gγ=4.5 from the Booster for better preservation of spin polarization. The betatron tunes are raised above 4.7 after beam injection to avoid crossing imperfection spin resonance. In this scheme with betatron tunes below half integer for proton injection, the betatron tunes have to cross the half integer after injection. The half integer crossing was in operation for NSRL which is less stringent on beam emittance, however not being used for RHIC operation. The advantage of this scheme is that one may be able to reduce the beta functions at the stripping foil as needed with the half integer quadrupole in the available current range.

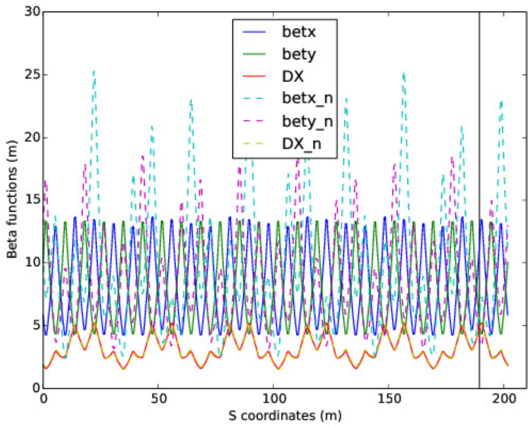

Figure 4: The distorted optics with tunes at (4.44, 4.47) is shown in dashed lines, and the nominal optics is shown in solid lines.

With the betatron tunes being kept at (4.44, 4.47), we were able to reduce the beta functions at the stripping foil down to (6, 4) m with available currents of the half integer quadrupoles in the simulation. The currents are qvstr1 = -4.66; qvstr2 = 10.67; qhstr1 = 13.44; qhstr2 = 19.12; iqhc = -121.85; iqvc = -96.30. The distorted Courant-Snyder functions around the Booster for this scheme are shown in Fig. 4.

SUMMARY

The current injection optics in the Booster requires betatron tunes be close to and above half integer. As a result, the tune spread of the proton beam may overlap with the half integer resonance due to the space charge force. With several simulation trials, we found two relatively practical alternative schemes to reduce beta functions at the stripping foil. The first scheme with the betatron tunes at (4.7, 4.75) requires new power supplies for the half integer quadrupole strings. The second one with the betatron tunes at (4.44, 4.47) works within the current range of the half integer quadrupole strings. However, the beam has to cross half integer resonance after injection which is yet to be demonstrated for polarized proton.

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ISBN 978-3-95450-182-3