INJECTION AND ACCUMULATION SCHEMES FOR THE AGS BOOSTER*

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Introduction

The AGS Booster now under construction[1] has three objectives. They are to increase the space charge limit of the AGS by preaccelerating protons from 200 MeV to 1.5 GeV, to increase the intensity of the polarized protons in the AGS by accumulating many linac pulses at 200 MeV, and to preaccelerate heavy ions from the BNL Tandem Van de Graaff before injection into the AGS. Therefore, we have to devise a different injection method for each of these three operations. The proton and polarized proton injection employs charge exchange of negative hydrogen while heavy ions must use multiturn injection into the betatron space. In this note we give a brief description of the heavy ion injection and high intensity proton injection (1), which are conventional and familiar to the reader, and describe the method of accumulating polarized protons in some detail. Figure 1 shows the Booster ring layout and the nomenclature for the magnets and straight sections.

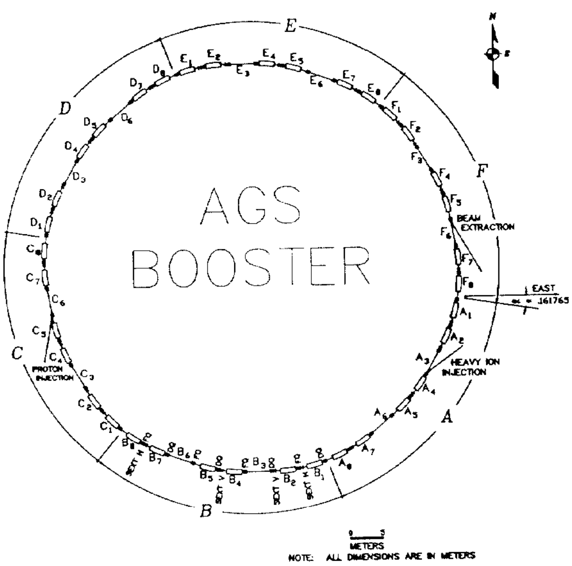


FIGURE 1

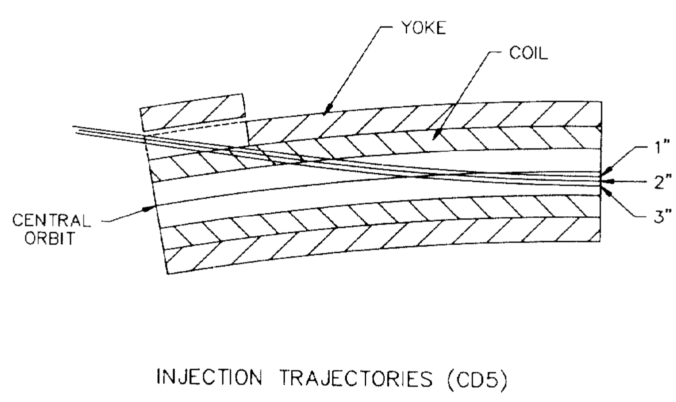
Heavy Ion Injection

For heavy ion injection we adopted conventional multiturn betatron stacking. At present the heavy ion beam from the Tandem Van de Graaff is transported to the C20 straight section of the AGS for direct injection. The beam will be further transported along the AGS tunnel to the L20 conjunction area of the AGS where the beam will enter the old 50 MeV linac tunnel and be injected into the Booster. An electrostatic injection septum will be placed in straight section A3 with the edge of the septum to be nominally 2 inches away from the central orbit. A DC orbit bump will move the closed orbit to the middle of the available aperture at this point. A programmed fast orbit bump will then be used to achieve multiturn injection into the horizontal betatron phase space.

High Intensity Proton Injection

The proton injection will use H^- injection, as is presently done on most of the world's accelerators, for both polarized and unpolarized proton operation. The advantage of charge-exchange injection is that one can continue to inject into already occupied phase space in apparent violation of Liouville's theorem. Therefore, one can arbitrarily shape the distribution of the injected proton density in the transverse phase space. In fact in space-charge limited machines like the Booster, one would like to populate the protons uniformly in the phase space.

For H^- charge-exchange injection, the closed orbit of the synchrotron is moved to the injection orbit where a stripping foil is located. For 200 MeV H^-, the foil is made of 100 - 200 $\mu g/cm^2$ of carbon. The foil is located downstream of dipole C5 which separates the circulating proton orbit from the injected beam from the linac. The injected beam from the linac must pass through the displaced yoke of the C5 dipole. Figure 2 shows the central orbit and three different injected orbits inside the dipole for a stripping foil located at 1, 2, and 3" from the central orbit. Because of the difference in sign of the charge, the circulating beam and the injected beam merge tangentially at the foil location. As in the case of the AGS, the stripping foil position must be experimentally determined to utilize the maximum available aperture and to achieve the maximum possible intensity. The final foil location determines the useful aperture. And a D.C. orbit bump, produced by using extra windings at three lattice dipole locations, will move the closed orbit to the center of this useful aperture. As the magnetic field ramps, the effect of this bump becomes smaller, but it is slower than the damping of the emittance.



INJECTION TRAJECTORIES (CD5)

FIGURE 2

A fast orbit bump is used to move the circulating orbit onto the foil. With the D.C. and fast bumps on, injection starts at the center of the Booster acceptance and moves toward the outside of the phase space as we decrease the size of the fast bump. The bump amplitude should decrease parabolically with a slope that matches the phase space area located at the orbit bump position. This will

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uniformly populate the available phase space. The fast bump is turned off at the end of injection and the size of the orbit bump at this time is the size of the injected beam plus the momentum space required after capture. We also locate a vertical fast dipole at the entrance of the C5 dipole to spread the beam uniformly in the vertical phase space.

Polarized Proton Accumulation

H^- charge exchange injection, if there are no other restrictions, enable one to inject for an arbitrarily long time or for many linac pulses. This is particularly useful for the Booster since only multiple scattering and space charge would eventually limit the length of injection process. In the conventional H^- injection scheme, both incoming ions and circulating protons go through the stripping foil every time they come around to the injection point, and the stripping foil is the major contributor to multiple scattering. The residual gas scattering in the Booster can be controlled by means of better vacuum but the growth of the emittance eventually causes loss of the polarized protons out of the admittance of the machine. For polarized protons, the problem is even more serious because the depolarizing resonance depends on the vertical emittance of the circulating protons. A new scheme to inject and accumulate H^- ions into a synchrotron was examined. The scheme attempts to minimize the vertical emittance growth and preserve the protons inside the horizontal admittance of the machine. A Monte Carlo simulation was made to compare the schemes with conventional injection. The calculation indicates that up to twenty-five linac pulses can be injected without excessive loss or vertical emitance blow-up.

The conventional H^- ion injection scheme[2] used at the AGS and at Fermilab utilizes a strip per foil arranged as shown in figure 3a. The orientation of both the vertical and horizontal phase space is matched to minimize the dilution of the phase space density. The foil covers one side of the phase space. In this arrangement more than half of the circulating beam goes through the foil every time it comes around to the injection point. An obvious improvement on this is shown in figure 3b, where the stripper is only wide enough to cover the incoming linac beam. The circulating beam has less chance to hit the stripper and the growth of the emittance is reduced. The scheme we are going to use is a variation of the latter. One can recognize the fact that there are two competing process in the phase space density dilution. One is from the multiple scattering and the other is caused by the phase space orientation mismatch.

The Booster injection point is chosen for the following properties. In order to minimize vertical emittance increase, we chose a location where the vertical beta function is as small as practical. The vertical condition imposed makes the horizontal beta function large. Since the emittance of the linac is much smaller than the Booster admittance, one can choose from a variety of phase space orientations. We chose one such that the vertical orientation of the phase space matches with the circulating beam and the horizontal phase space form a waist at the stripping foil (Fig. 3c). This arrangement of a narrow strip of thin foil is possible for the polarized proton injection because of the very low intensity of the beam thus there is no foil heating problem.

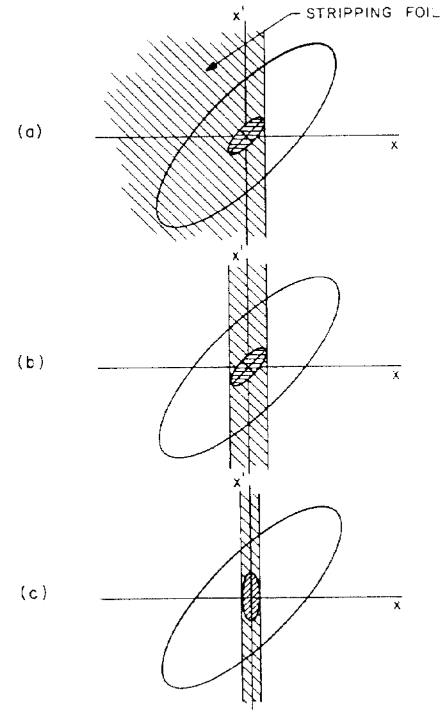

FIGURE 3

We examined many different horizontal beta functions for the injected beam and an empirical relationship was found. When the emittance and the beta function of the linac has the relation;

$$\frac{\varepsilon \text{ Booster}}{\beta \text{ Booster}} = 2 \ \frac{\varepsilon \text{ Linac}}{\beta \text{ Linac}}$$

with those of the circulating beam, the best stacking efficiency was found. In other words, when the angular spread of the linac beam is $1/\sqrt{2}$ of the angular spread of the circulating beam at the spatial center of the beam, the stacking efficiency is highest. Below that point particles are lost because of the phase space dilution caused by the mismatch and above the point beams are lost because of multiple scattering.

In the Monte Carlo study ten thousand protons were generated and transported around the Booster. Each time they came around we determined if they are inside the foil area. We added random angular kicks to simulate thin foil scattering to the particles inside the foil area, and examined if they still remained inside the admittance of the Booster. Figure 4 shows the result of the Monte Carlo calculation on the percent of beam loss versus the number of turns injected into the Booster. As can be seen in the figure one could stack as many as 12000 turns of beam with very good efficiency -- about 99%. A conventional injection method gives an efficiency less than 70%. Close to 90% efficiency is obtained for the case when the phase spaces have the same orientation. The errors are mainly from uncertainties in the foil thickness and uniformity.

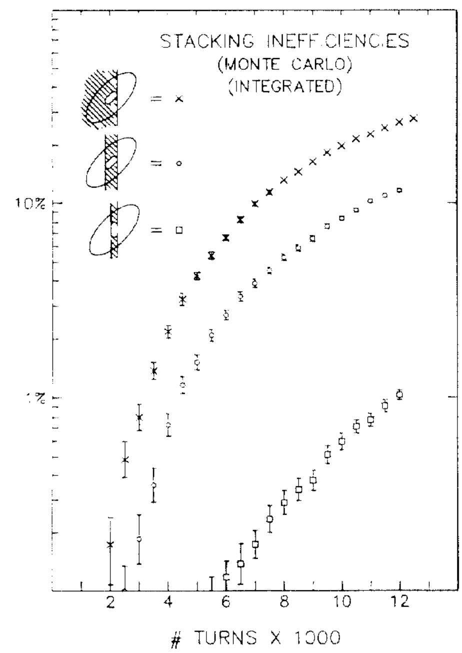

Figure 4

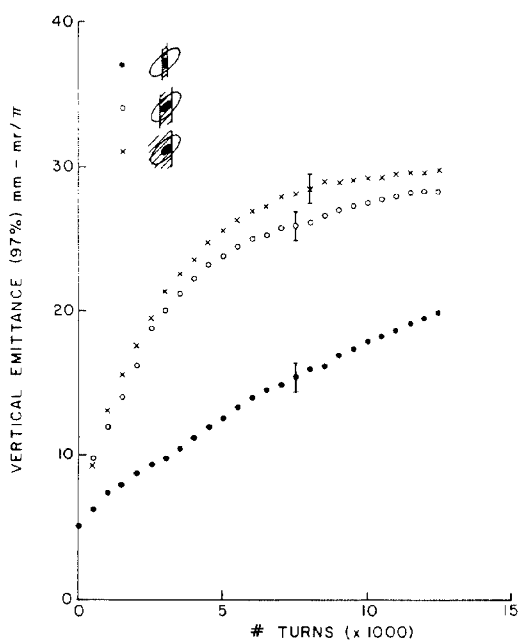

FIGURE 5

The vertical and horizontal emitance growth was monitored every 500 turns and the vertical result is shown in figure 5. The original linac beam has an emittance of 5 mm-mr and grows to 20 mm-mr at the end of 12000 turns for the proposed case. For the other two cases the emittance grows rather fast at the beginning but levels off around 30 mm-mr. This is not because the emittance stops growing but because the particles are lost out of the horizontal admittance of the Booster.

References

1. BNL informal report 34989 R, 1985
2. D.S. Barton and R.L. Witkover, BNL 26732, 1982.
   C. Hojfat, et al., IEEE NS-26 3149 (1979)