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MINIMIZING EMITTANCE GROWTH DURING H- INJECTION IN THE AGS BOOSTER *

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Abstract

As part of the efforts to increase polarization and luminosity in RHIC during polarized proton operations we have modified the injection optics and stripping foil geometry in the AGS Booster in order to reduce the emittance growth during H^- injection. In this paper we describe the modifications, the injection process, and present results from beam experiments.

INTRODUCTION

The RHIC complex consists of a 200 MeV LINAC, a Booster synchrotron that takes polarized protons up to 2.16 GeV/c ($G\gamma = 4.5$), the AGS that takes the beams up to 23.8 GeV/c ($G\gamma = 45.5$), and the two RHIC synchrotron rings, that take polarized protons up to 250 GeV/c ($G\gamma = 477.7$). The LINAC was upgraded with a new low energy transport system this year [1]. As a result it now delivers a factor of two smaller polarized proton beam emittance in both planes [1]. Nominal emittances in the past were on the order of 10 $\pi\mu m$, 95%, normalized. With smaller emittances, the percentage of emittance growth from Coulomb scattering on the injection foil in the Booster represents a significant fraction of the final emittance delivered to the AGS. To reduce this growth we have introduced thinner stripping foils and new foil geometries. In an attempt to further reduce the growth, we have changed the optics at injection to reduce the β-functions at the foil.

BOOSTER INJECTION

The LINAC produces an H^- beam, which is stripped of both electrons when injected into the Booster. The stripping foil is located on the inside acceptance of the Booster just downstream of the C5 main Booster sector bend. The C5 magnet has a channel in the backleg through which the H^- beam enters the field, and is bent to the left. Circulating beam is bent to the right. Figure 1 shows this geometry. A set of orbit deformation dipoles create a closed bump at the foil, such that beam is kept on the foil only during the injection pulse. The LINAC pulse is about 350 μsec long, while the booster revolution period is about 1 μsec. After 350 μsec the bump is collapsed and beam no longer hits the foil.

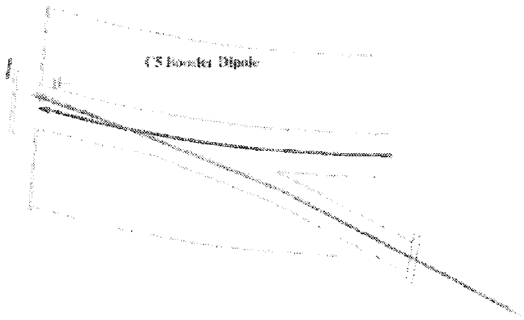

Figure 1: Injected beam trajectory through the Booster C5 main sector bend.

EMITTANCE GROWTH IN THE BOOSTER

The emittance growth in the booster is mainly caused by injection processes such as multiple scattering in the charge exchange foil and injection mis-match. The emittance growth due to multiple scattering can be approximated by

$$\Delta\epsilon_{rms} = \frac{1}{2} n\beta(s)\theta^2_{rms} \tag{1}$$

where n is the number of traversals through the foil and depends on the linac pulse length and shape of the foil, $\beta(s)$ is the matched β-function at the foil, and θ is the rms multiple scattering per turn, which depends on the foil thickness and material. To reduce the emittance growth we try to minimize each of these parameters. We have used new foil geometries, different linac pulse lengths, thinner foils, and different injection optics.

INJECTION FOILS

Each of five carbon foils mounted on a foil wheel may be selectively rotated into the aperture for H^- stripping. The available foils are given in table 1. There are basically 4 types of foils to choose from. Two of them are 100 $\mu g/cm^2$ full frame foils, which have been the standard foil used for polarized proton operation. There is one 200 $\mu g/cm^2$ foil, which is what we have used for high intensity unpolarized operation. Then there are two special foils, a strip foil, shown in fig. 2, and a stamp shaped foil, shown in fig. 3. These foils are designed to reduce the number of

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times the beam hits the foil during the injection process. The specialty foils are made by gluing a diamond like carbon (DLC) foil [2] to a frame and then using a laser cutter to produce the desired geometry [3].

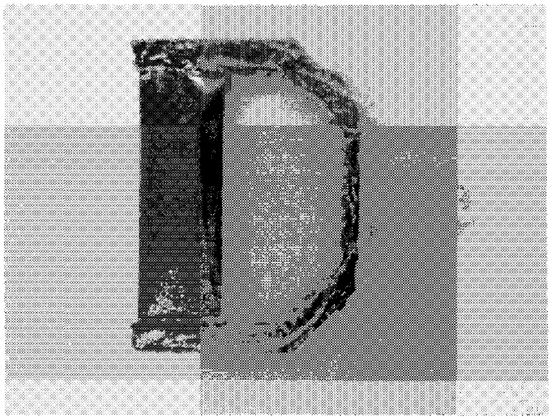

Figure 2: Diamond like strip foil.

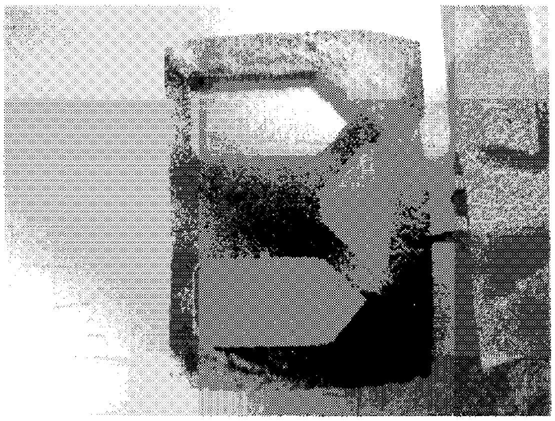

Figure 3: Diamond like stamp shaped foil.

Figure 4 shows the relative yields of H^-,H^0, and H^+ as a function of foil thickness. For high intensity unpolarized operation in the past, concern over radiation damage required that we use the very efficient 200 $\mu g/cm^2$ foil. But for polarized protons, the relatively low intensity allows us to optimize beam parameters by trading off some intensity to achieve smaller emittances.

REDUCED β-FUNCTIONS AT THE FOIL

The distortion of the β-functions in an accelerator due to quadrupole gradient errors is well known [4]. The amount of distortion is a function of the working point, the magnitude of the errors, and the distribution of the errors. Usually we want to reduce the distortion by exciting lattice quadrupoles such that the $2Q = N$ resonance can be approached or crossed without any beam loss or emittance growth. Driving a distortion is just a matter of exciting the same quadrupoles such that they increase the distortion rather than correct it.

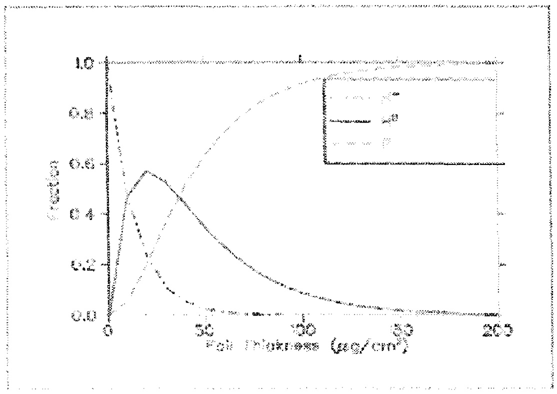

Figure 4: Relative yeilds of H^-,H^0, and H^+ as a function of foil thickness for a 200 MeV, H^- incident beam.

Table 1: Available foils on foil wheel.

No.	Thickness ($\mu g/cm^2$)	Edge location Inches from R_0	Type
1	No Foil	na	
2	130	-1.00	stamp
3	100	-1.00	full
4	200	-1.00	full
5	100	-1.00	full
6	130	-1.00	strip

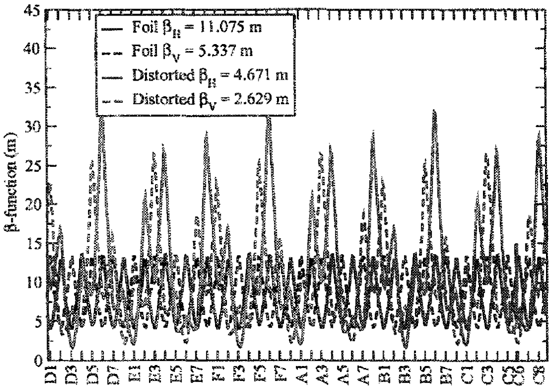

Figure 5: β-functions with and without the half-integer stop band distortion at Booster injection.

Figure 5 shows the injection lattice structure of the Booster for polarized protons with and without the half-integer stop band correctors exciting a distortion. Figure 6 shows the β-functions near the foil. Figure 7 shows how the horizontal distortion depends on horizontal tune.

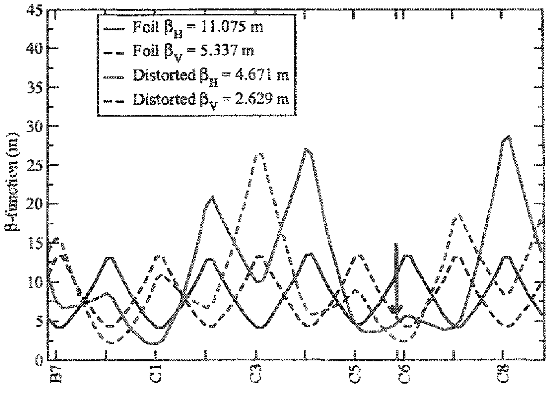

Figure 6: β-functions near the injection foil.

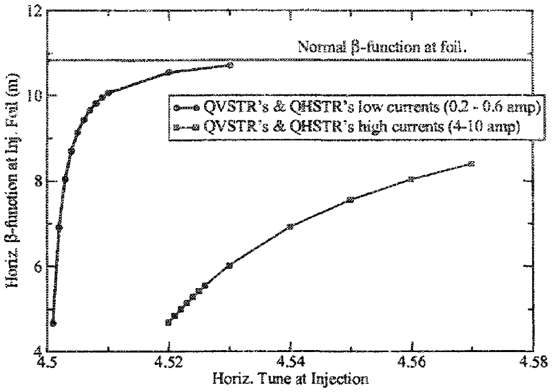

Figure 7: Tune dependence of distortion, for two different fixed stop band corrector strengths.

EXPERIMENTAL RESULTS

Our primary diagnostic for these studies is a beam profile monitor located at the start of the Booster to AGS transfer line. This profile monitor has wire spacing's of 1.5 mm, a horizontal β-function of 3.14 meters, and a vertical β-function of 16 meters. We studied emittance growth from the foil by scanning the amount of time the beam was held on the foil by making the LINAC pulse width very short (50 μsec) and adjusting the timing of the injection bumps. Figure 8 shows the horizontal emittances for different foils as a function of time spent traversing the foils.

Although this shows the predicted linear response to the time on the foil, the change in the slopes due to the change in optics is not consistent with predictions. While the emittance growth was reduced in the horizontal, the vertical emittance growth was not reduced. Nevertheless, the final overall emittances were smaller for the distorted injection optics. Some of that improvement is due to the new optics, but some is likely due to improved injection matching. The emittances for the two sets of optics are given in table 2.

We have many questions still to answer. Because the tunes are so close together during injection, large coupling is observed, resulting in mixing of the emittances. We continue to perform experiments to better understand the injection dynamics and to reduce the emittance growth from the foils.

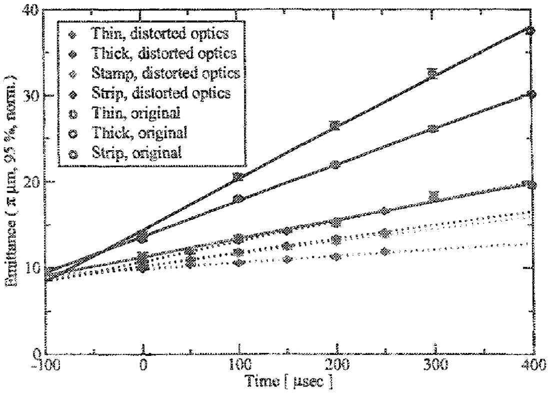

Figure 8: Emittance as a function of time spent on the foil, for different types of foils, with and without the distorted β-function lattice.

Table 2: Measured emittances for two different injection optics.

optics	$\epsilon_{Nx}^{95\%}$ $[\pi \mu m]$	$\epsilon_{Ny}^{95\%}$ $[\pi \mu m]$
Normal	14.2±0.5	9.3±0.5
Distorted	10.9±0.5	6.3±0.5

SUMMARY

The emittance growth due to Coulomb scattering in the injection H^- stripping foil has been reduced by using thinner foils and by reducing the β-function at the foil. These improvements have also resulted in improved machine performance, with as much as 15% higher transmission efficiencies.

ACKNOWLEDGEMENTS

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