THE BOOSTER TO AGS TRANSFER LINE: COMPARISON BETWEEN MODEL AND MEASUREMENTS *

K.A.Brown†, L. Ahrens, R. Bonati, D. Gassner, W. Glenn, H. Huang,
J. Morris, S. Nida, N. Tsoupas, V. Schoefer, K. Zeno
C-AD Dept., BNL, Upton, NY

Abstract

The Booster to AGS (BtA) transfer line was designed to match both ions and protons into the AGS lattice. For proton beam operation the only constraint on the optics is to define a match to the AGS lattice. For ion operation there are additional constraints introduced by a stripping foil in the upstream part of the transfer line. For polarized proton operation there is the complication that the AGS lattice is distorted by the presence of two partial snake magnets. In the 2008 polarized proton run it was observed that there was a significant optical injection mismatch. Beam experiments were conducted that showed disagreement with the model of the BtA line. In addition, these studies revealed some minor problems with the instrumentation in the line. A new model and more reliable measurements of the transfer line magnet currents have been implemented. Another series of experiments was conducted to test these modifications and to collect a more complete set of data to allow better understanding of the beam dynamics during the transfer and better understanding of the instrumentation. In this paper we will present the results of these experiments and the comparison to the new model of the BtA.

INTRODUCTION

Reaching the goals set for the RHIC polarized proton program requires looking at every stage in the acceleration process to ensure that both emittance and polarization remain as well preserved as possible. To preserve polarization, both horizontal and vertical emittances must be kept as small as possible [1]. Emittance growth can occur in a number of places in the process of getting the beams to RHIC. For example we expect emittance growth during H^- injection in the Booster on the stripping foil. We have developed techniques to minimize this growth [2]. We also have observed emittance growth during AGS injection.

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 rings, that take polarized protons up to 250 GeV/c ($G\gamma = 477.7$). The focus of this work was to carefully measure and analyze the transfer of the beams from the Booster to the AGS. The goals were to improve our model of the transfer process and to develop strategies for improving the match between the transfer line and the AGS injection optics. The injection optics are highly distorted by the presence of two Siberian snakes. So, an important aspect to developing a match is to develop a good model of the lattice structure in the presence of the snakes, associated correction quadrupoles and orbit distortions.

The beam experiments exploited all the available instrumentation and attempted to generate as many cross checks as possible. For example, we made R_{12} transfer matrix measurements (displacement vs excitation), dispersion measurements, and performed emittance scans. We studied power supply calibrations and magnet hysteresis. Although we cannot completely cover all the measurements we made in this short report, we will describe below some of the successes and some problem areas uncovered during these studies.

For the studies we used three different sets of BtA optics, the optics used for injection during the previous polarized proton run, a set of optics developed to match into the "bare" AGS lattice, and a set of optics in which all the quadrupoles were turned off. The bare AGS lattice consists of exciting just the AGS main, combined function, bending magnets, though the correction dipoles were adjusted to allow the beam to survive and accelerate. The various snake systems as well as the quadrupole and sextupole correction strings were not powered.

DISCUSSION

The BtA line consists of 15 quadrupoles, two major bends, a stripping foil for operations with heavy ions, and four sets of profile monitors. In the Booster the process of extraction begins with a full aperture kicker that bends the beam off a distorted equilibrium orbit into a thick septum magnet. The septum bends the beam outward by 143 mrad. The orbit is distorted in order to place the circulating beam close to the septum.

Booster Extraction

Since the BtA model needs initial conditions based on the state of the Booster lattice (tunes and dispersion, for example) a good model is needed of the extraction process and the extraction devices. For model comparison, measurements were made of the orbits, dispersion, and changes in trajectory.

The Booster model has been well tested in the past [3]. To test the model of the extraction process we measured orbits under different conditions.

* Work performed under Contract Number DE-AC02-98CH10886 with the auspices of the US Department of Energy.

† kbrown@bnl.gov

The extraction orbit distortion (bump) is created using four power supplies connected to auxiliary windings on four Booster main dipoles. Figure 1 shows the model of the resulting 4-bump, with measurements. Along with these measurements each of the power supplies was individually scanned. For two of the power supplies the back-emf from the ramping Booster main magnet power supply causes significant current to flow in the windings. For proper modeling it is important to use the readbacks of the four power supplies and these readbacks need to be well calibrated. In each case the agreement with the model was consistent with the agreement shown in figure 1.

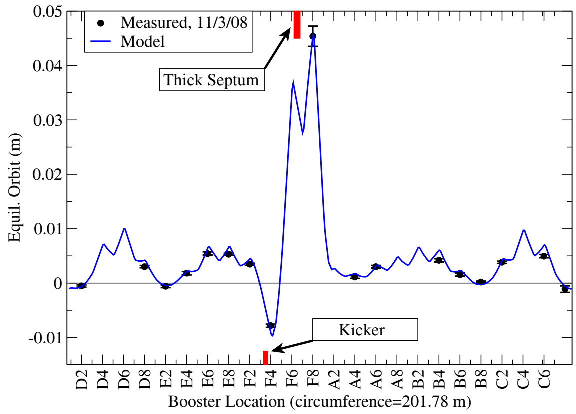

Figure 1: Booster extraction orbit distortion.

Power Supply Calibration

Calibration of the quadrupole power supply currents, as we see them in our controls interfaces, requires close interaction between the power supply group, the controls group, and the physics group. Each power supply has multiple A/D and D/A conversions. To check that these conversions were done correctly, the controls interface boards were bench tested and calibrated. After corrections were made the readback and setpoint values were cross calibrated using DCCT's and calibrated shunts. In fact, a few power supplies were found to be as much as 5 to 10% out of calibration (corresponding to 25 to 50 amp errors, for high currents).

Although the BtA quadrupoles are operated DC, they do occasionally get tuned and they do occasionally trip off. If hysteresis is significant it can add another error into the model. To measure the effect of the hysteresis we systematically adjusted the quadrupole currents by large amounts and measured changes in R_{12} and in actual beam sizes. Differences were observed, but they amounted to less than a one ampere change in the power supply current.

Instrumentation and Controls

Both the controls and instrumentation groups were directly involved in these experiments. Significant improvements were made in both the control of beam profile systems and the fitting of the beam profiles to get realistic beam sizes and average positions. Complete logging of data allowed for more detailed off-line processing, which allowed on-line processing to be improved. We learned that whenever possible we need to keep the raw data, for both background subtraction and wire by wire response, as well as data from other instruments used for cross correlations or normalization.

R_{12} Measurements

Measuring the amount of deflection (in mm) at a profile monitor as a function of a particular steering magnet is a direct measurement of the lump R_{12} matrix element between that steering magnet and the profile monitor. Comparing these measurements to the model is a very good test of the model, assuming we know the amount of change in the bend of a particular steering magnet.

Figure 2 shows measured R_{12} values along with model predictions for the case in which the quadrupoles were turned off. Figure 3 shows the case for the matched optics. Clearly the model has an error with respect to DH23 (the large 30 degree bend in the line), while agreement with the other steering magnets is generally good.

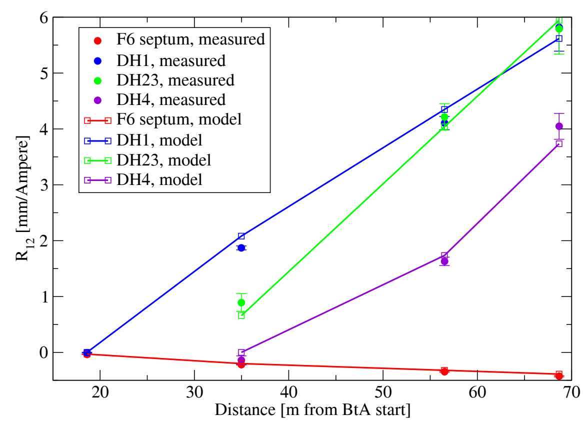

Figure 2: R_{12} measurements and model predictions; quadrupoles off case. Data is shown only at the four profile monitor locations. Error bars show the statistical spread of 5 to 10 independent measurements.

Dispersion Measurements

Figure 4 shows the measured dispersion at the four profile monitors in the line along with the model prediction for the quadrupoles off case and the matched optics case. Agreement is relatively good, although there appears to be a systematic offset in most of the data points. This is not yet understood.

Quadrupole (Emittance) Scans

In these experiments a single quadrupole current is adjusted, causing the beam size on a single profile monitor to go through a waist(see [5] for a description of the

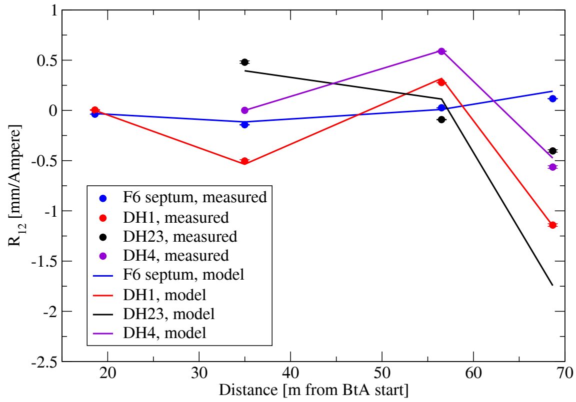

Figure 3: R_{12} measurements and model predictions; matched optics case.

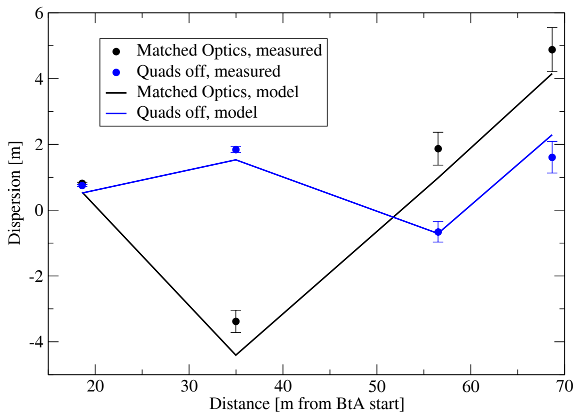

Figure 4: Dispersion measurements and model predictions.

method). Fitting the data allows extracting the emittance and Courant-Snyder parameters [4] at that quadrupole. Figure 5 shows an example of a scan using Q1. Table 1 shows the analysis results of scans using Q1 and Q2. Q1 is a vertical focus quadrupole, so the results given are in the vertical plane. Q2 is a horizontal focus quadrupole, so results are in the horizontal plane.

Table 1: Emittance Scan Results. Q1 Focuses Vertically. Q2 Focuses Horizontally.

	fit β (m)	**fit α**	**mad β (m)**	**mad α**	**fit emitt. (95 % $\pi\mu$m)**
Q1	18.43	-2.12	20.7	-2.38	10.7
Q2	3.88	-0.75	5.03	-0.86	12.9

Building a Model

Although we started with a fifteen year old model of the BtA line, we found we needed to go through that model with extreme care. For example, a comparison was made between the model definitions and the mechanical survey of the elements as well as going into the tunnel with a tape

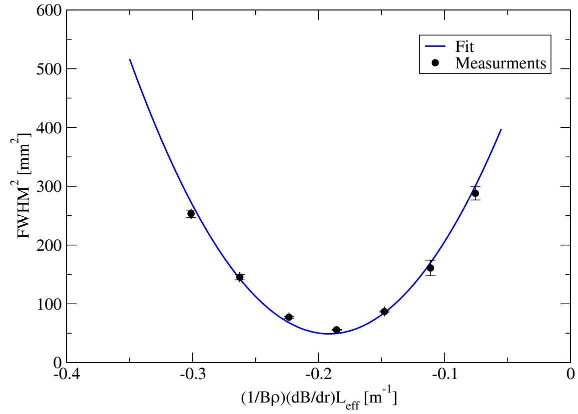

Figure 5: Emittance scan using BtA Q1.

measure to check some of the distances.

Two significant improvements were made to the BtA model. First, we improved the methodology in how we model the BtA by including on-line settings and by carefully determining initial conditions.

The second improvement concerns the model of the 30 degree bend in the line. This bend consists of two 10 degree (Booster sector) magnets, each being overdriven to create a 15 degree bend. To tackle this problem we built a magnetic model of these magnets and reconstructed the *madx* © [6] definition such that the core focusing and edge focusing were separately defined.

SUMMARY

With an improved model of the Booster to AGS transfer we have found very good agreement with most measurements. There are still differences that we do not understand. We continue to work on the model and the comparison to beam based measurements.

REFERENCES

[1] H. Huang, et al, Phys. Rev. Let. **99**, 154801 (2007)

[2] K.A. Brown, et al, "Minimizing Emittance Growth during H^- Injection in the AGS Booster", These Proceedings

[3] K.A. Brown, et al, "A High Precision Model of AGS Booster Tune Control", Proceedings of EPAC 2002, Paris, France, pp.548-550 (2002).

[4] E. D. Courant and H. S. Snyder, Annals Phys. **3**, 1 (1958) [Annals Phys. **281**, 360 (2000)]

[5] M. Minty and F. Zimmerman, "Measurement and Control of Charged Particle Beams", Springer Verlag, Berlin (2003)

[6] H. Grote and F. Schmidt, "MAD-X - An Upgrade from MAD8", Proceedings of the 2003 Particle Accelerator Conference, Portland, OR, pp. 3497-3499 (2003)