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Synopsis of BTA Steering Data and Future Directions

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1 SUMMARY

At various times throughout the last run steering data for the BTA line were gathered, the goal being to understand the line's optics. The data acquisition and analysis procedures are outlined, along with the analyzed data. Results with regard to the beamline optics are inconclusive. Further experiments are proposed, which should resolve the ambiguities.

2 INTRODUCTION

The Booster to AGS (BTA) transfer line is an integral part of the BNL hadron acceleration facility. A quantitative model for the BTA line will be invaluable for predicting and controlling transverse emittance in the AGS. In the near future, with low intensity, smoothly matching the beta functions and the dispersion have significant promise for reducing the fast losses observed in the AGS. As the push for intensity continues, well controlled painting in transverse phase space may reduce halo growth and subsequent beam loss caused by collective effects (eg. space charge induced tune shift).

A quantitative model for the BTA line is under development, using the computer program MAD. The locations of the various optical elements in the model have been checked against survey data and the feeling is that the locations assumed in the model are OK. The longitudinal positions of the elements in the model are given in Table 1.

The bending strengths of the dipoles, and the focusing strengths of the quadrupoles are calculated using field measurements. For all devices except quadrupoles 5, 6 and 7 the focussing strength was obtained using the readback current values and the calibrations in the set of tech notes by Ed Bleser. For quads 5 through 7 the following relationships were used.
I5(true)=0.857*I5(set) + 142A
I6(true)=0.837*I3(set) + 159A

Table 1: Longitudinal Positions of selected BTA elements

element	longitudinal position (m)
DHF6A	0.86
DHF6B	2.19
QV1	5.44
DH1	6.39
QH2A	7.32
QH2B	7.99
QV3	9.34
QH4	11.21
DH2	13.19
QV5	15.12
DH3	17.57
QH6	19.52
MW060	20.71
QV7	21.42
QH8	30.42
DH4	31.67
QV9	33.99
QH10	36.97
MW125	42.25
DH127	42.80
QV11	43.59
DV141	47.40
QH12	48.19
DH158	52.77
QV13	53.56
MW166	54.40

I7(true)=0.888*I7(set) + 147A

Unfortunately, the model is not in quantitative agreement with the machine. The discrepancies began while trying to match the BTA line to the AGS. Quadrupole strengths which should have decreased the beam size in the AGS had little effect on losses in the AGS. As a test of the BTA line optics, a set of quadrupole currents were calculated which should have made the horizontal position at multi-wire 060 (MW060) insensitive to changes in the current in the extraction septum. When these currents were implemented the change in position with respect to current dx/dI at MW060 was much larger than expected.

3 STEERING DATA

The failed attempt at imaging the extraction septum at MW060 was worrisome. Several other imaging schemes were tried. Initially these studies were performed in a somewhat cavalier manner, resulting in data of limited usefulness. After a few tries it was clear that a systematic study was in order.

It was decided that steering data were preferable to beam size data, since steering is independent of the beam's initial conditions (for negligible losses). The imaging test seemed like a good idea, so optics for various object image situations were calculated. Initially only dipole magnets were used. Later on, a scheme using quadrupoles was also tried.

3.1 Dipole Measurements

For a given set of quadrupole currents, the current in a dipole magnet was set to a given value. The average position of the beam at a given multiwire, averaged over all cycles for a given user were recorded for ~ 10 supercycles. The value of the dipole magnet current was changed and the process was repeated. Raw data generally consisted of between 3 and 5 sets of average position values. Occasionally, a significant linear trend in the data for a single setting of currents was observed. These events were rare because apparently random shot to shot variations swamped the effect, unless the series of position measurements was very long. The dipole magnet current was varied in a way to minimize the effect of overall machine drift. A series of currents like $(0, 10, -10, 20, -20)$ would be used instead of $(-20, -10, 0, 10, 20)$. Typical standard deviations for a single set varied between 0.2mm and 0.5mm. The average position values for each set of currents were calculated and a straight line was fit to the averaged data to obtain the expected position as a function of dipole magnet current. Using the measured field integrals as a function of

Table 2: Dipole Steering Data

Devices	x'_E	x'_M	$\Delta\ell$	L
	(mm/mrad)	(mm/mrad)	(m)	(m)
DH2-3-166	2.7 ± 0.03	0.053	3.1	39
DH2-3-125	1.4 ± 0.2	0.616	0.6	27
DH1-166	4.5 ± 0.6	3.83	0.8	48
DH4-166	-0.52 ± 0.03	-0.25	0.13	23

current, and the rigidity of the beam resulted in the experimental value for the change in position at the multiwire as a function of bending angle in the dipole.

$$x'_E = \frac{dx_E}{dI}\frac{dI}{d\theta}, \tag{1}$$

where dx_E/dI was the slope of the line fitted to the experimental data as a function of magnet current and $dI/d\theta$ was the calibration constant. One standard deviation errors for the experimental results were derived from the one standard deviation errors for the least squares straight line fit.

For comparison purposes, the experiment was simulated using the model. The simulations were carried out using the error capability of the MAD program. An error of 1 mrad was introduced in the dipole magnet of interest and the beamline model, using the readback values of the quadrupole currents, was run. The change in position with respect to bending angle as calculated by the model is denoted as x'_M. Data for dipole steering in the BTA are shown in Table 2 The first column of Table 2 gives the dipole and multiwire used in the measurement. For example, DH2-3-166 means that the series set of dipoles DH2 and DH3 were varied and the position measurements were made using MW166. In all cases, the setpoint currents were close to model currents calculated to result in no variation in position with current.

As is clear from Table 2 none of the experimental results are within one standard deviation of the model predictions. The distance the multiwire would need to be moved (according to the model) so that agreement between the data and the model would be achieved was calculated. These distances are shown in column 4. A positive value of $\Delta\ell$ means that the location in the model, corresponding to the measured values, is downstream of the multiwire. The total distance between the dipole and the multiwire is given in the last column. If one prefers to think in terms of momentum error, the ratio $\Delta\ell/L$ is of order the required fractional change in momentum for the observations and the model to agree. This same ratio is of order the fractional error in

Table 3: Quadrupole Steering Data

Quad	x'_{125E} (mm/kA)	O_{125} (mm)	x'_{166E} (mm/kA)	x'_{166M} (mm)
Q6	59 ± 3	5.8 ± 0.3	0 ± 6	-0.2
Q9	-36 ± 5	-9 ± 1	0 ± 2	-0.3
Q7	8.9 ± 0.7	1.2 ± 0.1	-1.9 ± 0.7	-0.2
Q4	-140 ± 40	10 ± 3	40 ± 15	19

the quadrupole gradients which would account for the discrepancy. Only the measurement using DH4-166 yields errors in quad strength less than 1%.

3.2 Quadrupole Steering Data

If the beam is not centered in a quadrupole, changing the strength of the quadrupole results in a transverse kick. Using the same techniques as in the previous section the change in position with respect to current for quadrupole multiwire combinations were obtained. In all cases the optics were chosen to image the quadrupole at MW166. The change in position with respect to current at MW125, x'_{125E} was also obtained. Using the model, the offset in the quadrupole needed to obtain the observed variation at MW125 was calculated, O_{125}. This offset was then used to predict the variation of position with current at MW166, x'_{166M}. All the data presented are tests of horizontal optics and are summarized in Table 3.

Most of the data in Table 3 give reasonable results for the quadrupole offset, but the error bars are large.

4 DISCUSSION OF THE DATA

The data of the previous section show that something is clearly wrong with the model of the BTA line. The fact that all the values of $\Delta\ell$ in Table 2 are positive may be significant. In all cases, the measured data correspond to a point that the model says should be downstream from the multiwire. More horizontal focusing is present in the real machine than the model predicts. This may correspond to a weak vertical quadrupole. On the other hand, fair agreement exists for a large part of the line. One is hard pressed to make any predictions with current data.

5 FUTURE STUDIES

Currently, tests of the BTA magnets are underway.

Future studies of the BTA line will be similar to those already done, but in greater detail. It is proposed that all steering dipoles be tested, both horizontal and vertical, and that all available tranverse position data be gathered on a shot to shot basis. As of now there are three fully functional multiwires and I take these three as present. The repair of MW006 and the functioning of the 6 beam position monitors are not assumed, but would be helpful. It would be best if data for each booster cycle were kept separate, minimizing uncertainties associated with differences over the cycles.

The decision as to whether a given shot was usable would be decided on the basis of the total current impulse given to the multiwires, or the presence of aperturing. Initially the location of the beam centroid will probably be estimated using the weighted average of the multiwire bins. Curve fitting to the data may come later.

Six quadrupoles and five dipoles can be checked in a fairly direct fashion, corresponding to three strings. These sublines are:
1. DH2, QV5, DH3, QH6, MW060
2. DH4, QV9, QH10, MW125
3. DV141, QH12, DH158, QV13, MW166.

In each of the three strings there are two quadrupoles. For definiteness, I'll consider the first string. The experimental technique would be to:
1. turn off QV5
2. minimize scraping by adjusting upstream elements
3. vary DH2-3 making measurements using MW060
4. change QH6
5. repeat step 3
6. switch roles of QV5 and QH6 and do it again.

This sequence of measurements is rather delicate in that there is little phase advance between the elements. Rapid switching between the various current settings and lots of repetition would be needed to check for moving baselines etc. However, it is possible to check the calibration of all the optical elements in this way, especially if it is possible to get clean transmission with both quadrupoles off. The other two strings could be checked in similar fashion.

After the responses of the strings are fully understood, the testing could be extended. For example, QV11 could be checked using DH127 while DH2-3 is used for QV7 and QH8. The analysis above results in complete knowledge of everything between DH2 and MW166, inclusive. There are three multiwires, so the horizontal orbit is fully determined (including momentum error) and the vertical orbit is overdetermined, at least to first order. Given such a base, it seems that working upstream from the DH2-MW166 string should be fairly robust. Checking elements downstream of MW166 requires pickups in the AGS which give single turn data. The L20 flag would be helpful if the signal could be digitized.

Future experiments with the BTA line assume an automated data logging system, akin to the routine Joe Skelly uses in his bmline_emit program except that data from more than one multiwire needs to be taken. The variation in setpoint currents could be accomplished by the experimenter, especially if he had only one menu to worry about.

The amount of time required to do the measurements depends on the amount of time required to debug the data acquisition software, and the stability of the extracted beam. If everything works most of the time, it is expected that four half shifts (16 hours total) will be sufficient. At least a day or two between each half shift will be needed to analyze the previous data.