

## USER CONTROL OF THE PROTON BEAM INJECTION TRAJECTORIES INTO THE AGS BOOSTER

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### INTRODUCTION

The 1.5 GeV(proton) Booster Synchrotron nearing completion at the AGS will get its 200 MeV beam from the linac, via a 34.9 m long linac-to-Booster transport line, LTB. LTB branches off from the existing linac-to-AGS transport line, HEBT, approximately 18.4 m downstream from the linac. A schematic layout of LTB is shown in the bottom part of Fig. 1. The four dipoles, DH2 through DH5, which are identical and are operated in series, provide a 126° bend in the line.

We have employed three strategies for implementing control of the trajectory, namely: (1) a global correction (2) a local correction (3) a zeroing correction. These, as well as their implementation, will be discussed. Operating experience obtained from early commissioning runs will be given.

The hardware used to implement the correction schemes are the beam position monitors, BPMxxx, orbit correctors, DHxxx and DVxxx, and multiwire profile monitors, MWxxx. The quads are QHxxx and QVxxx.

### THEORY

#### Global Orbit Correction

The objective of this scheme is to minimize, in a least squares sense, the displacements from the design trajectory at the position monitors. The beam positions at the monitors are read, and the additional kicks needed at the orbit correctors to give a least squares correction of the trajectory are found. The mathematical treatment[1] is summarized here:

Let  $x_i$ (x or y),  $i = 1, \dots, m$  be the displacement at the  $i$ th BPM before correction and  $T_{ij}\theta_j$  be the displacement of the trajectory at the same BPM due to a kick,  $\theta_j$ , by corrector  $j$ ,  $j = 1, \dots, n$ .

$$T_{ij} = \begin{cases} \sqrt{\beta_i \beta_j} \sin(\phi_i - \phi_j), & s_i \geq s_j \\ 0, & s_i \leq s_j \end{cases} \quad (1)$$

where  $s$  is distance along the line,  $\beta$  a Twiss function and

\* Work performed under the auspices of the U.S. Department of Energy.

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$\phi$  the phase advance. Defining a norm

$$S = \sum_i \sum_j (X_i + T_{ij}\theta_j)^2 \quad (2)$$

then the kicks,  $\theta_j$ , which minimize the orbit displacements are found by solving the system of equations:

$$\partial S / \partial \theta_j = 0 \quad (3)$$

with the help of the Householder transformation.[2]

This correction may be done on any section of the line, provided it has enough correctors and monitors.

#### Local Orbit Correction

The purpose of this correction scheme is to find the condition for the beam to pass through the center of a quad, making use of the fact that such a beam suffers no deviation. The scheme requires a corrector upstream of the quad, and a position monitor downstream. We obtain the beam positions for the normal excitation current of the quad, and for two other currents, one higher and one lower. The slope of the curve drawn through these points, in a graph of position versus quad current, measures the deviation due to the quad. Changing the current in the corrector by a small amount and repeating the measurements give data for a second line on the graph. From the corrector current change and the change in slopes of the curves, the current needed to give a line of zero slope (no deviation) is found.

#### Zeroing

Sometimes, it is desirable to have the beam parallel and on axis at the end of the line segment which has been globally corrected. The zeroing algorithm provides a way to do this. After the global correction has been executed, the last two position monitors in the line segment are read, and the additional kicks in two correctors upstream of them, necessary to bring the beam on axis, are calculated. Zeroing can be used even if the global correction was not executed.

If  $x_{m-1}$  and  $x_m$  are the orbit displacements at the  $(m-1)$ th and  $m$ th BPM's, the kicks,  $\theta_{n-1}$  and  $\theta_n$ , in the last two correctors are given by:

$$\theta = -T^{-1}\bar{X} \quad (4)$$

where  $T$  is the response matrix defined in Eq. (1). With small variations, the zeroing algorithm also allows one to bring the beam to a given non-zero displacement and angle at a chosen point along the line.

The data required in Eq. (1) are obtained from MAD[3] for a run with the MAD model of LTB. MAD must be rerun whenever the tune of the quads in the line is changed.

### SIMULATION

The first and third correction schemes were extensively tested in simulations on the Apollo Domain network used to control the Booster and its beam transfer lines. Distorted orbits were generated by small random misalignments of all the magnets in the line.

### IMPLEMENTATION

#### Hardware/Software Environment

The LTB Steering software is currently being used on a Hewlett Packard/Apollo 4500 workstation running the Apollo Domain operating system. The software was developed using the C++ programming language and uses the Apollo Dialogue graphical user interface (GUI). User interaction is through a GUI library developed in-house.

Setpoint selection and data transmission from magnets and instrumentation occurs through a hierarchical communications pathway. A Device (a magnet, for example) transmits its data (its current and status) to a Controller, which also collects data from many other Devices. The Controller is periodically scanned for its data by a Station. The Station acts as a final collector of data from its set of Controllers before data are sent across a local area network (LAN) to a Host. The Host takes the data off the LAN and sends it to its clients (the application software). A schematic representation of the basic architecture is shown in Fig. 3.

#### Program Flow

On entering the LTB Steering program, the user selects a correction method (global or local), a plane (horizontal or vertical) and a section or set of sections within the LTB line where the program will be focused. Initial magnet settings can be set through menu items within the program or through a companion instrumentation program. The user can also ask for the collection of data from one or both multiwire profile monitors in the LTB line, as well as from the seven BPMs. The centroids of the profiles are then used as additional position measurements within the correction algorithms.

#### Global

To run the global correction algorithm, the user first chooses the menu item which collects the necessary data. This includes the current set of corrector values and positions. In addition, the computer checks quad settings and, if changed, reruns MAD and computes a new response matrix,  $T_{ij}$  above. Once the algorithm is run, the program displays both the current corrector and position values and the corresponding values predicted by the global algorithm. The user then has the option of sending these predicted corrector settings to the magnets after which a new set of corrector and position measurements are obtained and displayed. The final display shows position and corrector setting plots using old, predicted and new values. The user can undo these new corrector settings through a menu option.

#### Local

To begin the local correction algorithm the user selects a corrector, a quadrupole, and a position monitor. The user can then change the corrector and quadrupole step sizes, if desired, from their default values. Selecting the menu item to run the local correction algorithm then causes the computer to vary the quadrupole and corrector by their respective step sizes while collecting a new position measurement after each change. The results are plotted on the screen, and the slopes of the two curves are used to determine the corrector setting which would cause a similar dataset to have a zero slope. If the user chooses to use the newly calculated corrector setting, new position measurements for the entire line are collected and displayed. As with the global implementation, the user can rollback to the original corrector setting.

### CONCLUSIONS

The steering algorithms applied to our earlier tests of the proton injection line into the Booster proved flexible and useful to allow for a clear transport of the beam along the line. Figures 1 and 2 show the results of the global and local orbit correction in the LTB line. The experience will be important to implement similar methods for correcting the orbits in the Booster Synchrotron Ring and in the other transfer lines.

### REFERENCES

1. F.Z. Khiari and A.U. Luccio, private communication.
2. A SLATEC routine. See also, W.H. Press et al., Numerical Recipes, Cambridge University Press, 1988, pp. 59.
3. F.C. Iselin and J. Niederer, the MAD Program, Version 7.2, CERN/LEP-TH/88-38.

# LTB Steering - Mon Apr 29 16:48:29 1991

Correction mode: global  
Plane: vertical  
Section(s): 3  
PPM user: Booster Protons 1

Groups to acquire: 1  
Cycle display: average  
Group display: average

Proton type: PRO

○ Old data  
□ Current data  
△ Predicted data

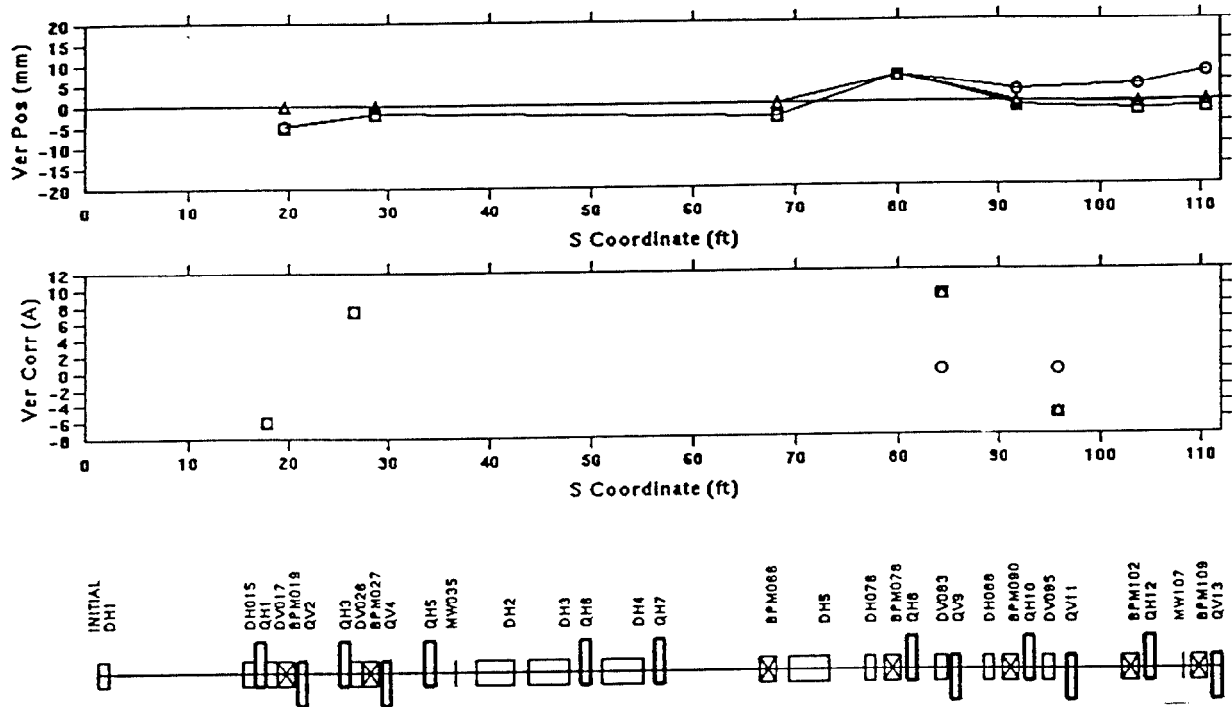
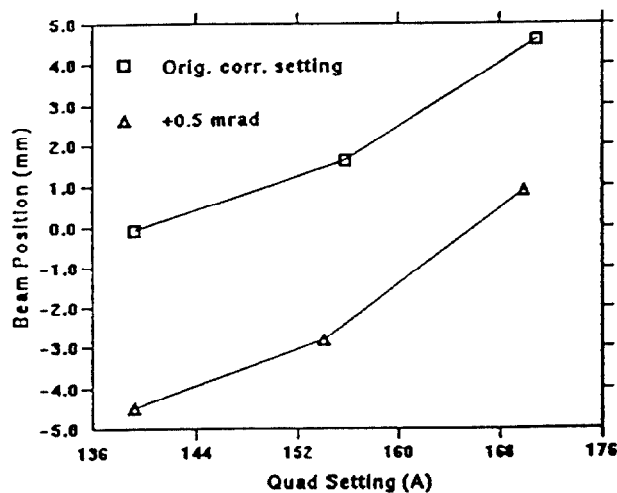


Fig. 1. Global steering algorithm in the LTB-vertical plane.



Value to yield a zero slope:

Angle (mrad) = -3.09

Current (A) = -19.4

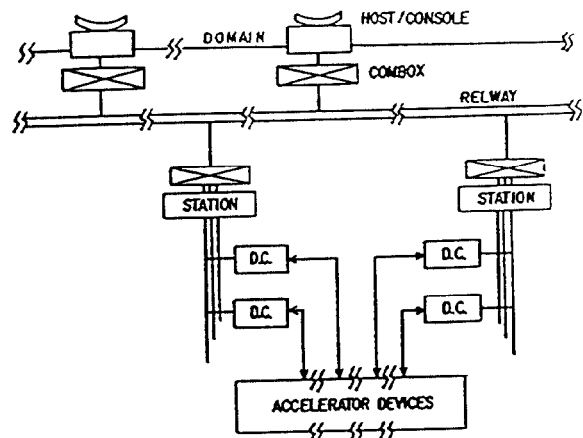


Fig. 2. Local steering algorithm in the LTB.

Fig. 3. Hardware/software environment.