Ring Diagnostics and Consistency Test of the Model for the AGS Booster*

Alfredo Luccio and Elliot H. Auerbach
AGS Dept., Brookhaven National Laboratory
Upton, NY 11973

Abstract

From a systematic analysis of readings of the beam position monitors in the AGS Booster ring, combined with the transfer matrices between a few locations in the ring, calculated with MAD [1], the consistency of the model of the lattice has been tested. This technique has enabled us to (i) detect errors in the machine that subsequent survey during shutdown has confirmed, and (ii) to measure the actual circulating beam momentum offset. The method has proved rather general and convenient for accelerator diagnostics as part of a model-based accelerator control system and extensions are suggested.

I. INTRODUCTION

We had two motivations for this work. The first was specific: to find the displacement of the closed orbit and its angle and the momentum offset of the beam in the AGS Booster in order to calculate correct orbit bumps for injection, extraction and so on. The second was general: to set up a model based [2] algorithmic tool to search systematically for errors in the machine lattice and to check the agreement between the real machine and the model. For this, we have used the orbit data, that is, the values of the orbit displacement at each of the 22 orbit position monitors in the ring. In this work we have considered the effect of orbit measurement errors only as "noise". Indeed, the purpose of the present paper, for lack of space, is mainly to show the principles of operation of the tool and to describe a few examples of application to the AGS Booster.

II. THEORETICAL BASIS

Consider three beam position monitors, or BPM's: i, j, k. Here, beam position readings are

$$\left(x_i\ x_j\ x_k\right). \tag{1}$$

At BPM locations, the model (MAD) gives dispersions and their derivatives

$$\left(\eta_i\ \eta_j\ \eta_k\right);\left(\eta'_i\ \eta'_j\ \eta'_k\right). \tag{2}$$

The transfer between BPM-i and BPM-j is described by

$$\left[\begin{pmatrix} x \\ x' \end{pmatrix} - \frac{\delta p}{p}\begin{pmatrix} \eta \\ \eta' \end{pmatrix}\right]_j = \mathbf{M}^{(i,j)}\left[\begin{pmatrix} x \\ x' \end{pmatrix} - \frac{\delta p}{p}\begin{pmatrix} \eta \\ \eta' \end{pmatrix}\right]_i, \tag{3}$$

with the (unknown) momentum offset of the beam

$$\delta p/p,$$

and transfer matrices between BPM's, whose elements are expressed in terms of the machine's Twiss functions α, β, ϕ

$$\mathbf{M}^{(i,j)} = \begin{pmatrix} A & B \\ C & D \end{pmatrix}. \tag{4}$$

Eq.(4) gives

$$\begin{cases} C^{(i,j)}x_j = x'_i - D^{(i,j)}x'_j + F^{(i,j)}\,\delta p/p \\ C^{(j,k)}x_k = x'_j - D^{(j,k)}x'_k + F^{(j,k)}\,\delta p/p \\ x_i - A^{(i,j)}x_j = \quad B^{(i,j)}x'_j + E^{(i,j)}\,\delta p/p \\ x_j - A^{(j,k)}x_k = \quad B^{(j,k)}x'_k + E^{(j,k)}\,\delta p/p \end{cases}, \tag{5}$$

with the definitions

$$\begin{aligned} E^{(i,j)} &= \eta_i - A^{(i,j)}\eta_j - B^{(i,j)}\eta'_j \\ F^{(i,j)} &= -\eta'_i + C^{(i,j)}\eta_j + D^{(i,j)}\eta'_j \end{aligned}. \tag{6}$$

Eqs.(4) are four to be solved for the four unknown quantities, the beam angle at the chosen PUE's and momentum offset

$$\left(x'_i\ x'_j\ x'_k;\ \delta p/p\right). \tag{7}$$

Among several possibilities, let us choose the following strategy. Survey all PUE's in the ring in groups of three, as follows

1,2,3 2,3,4 3,4,5 ....

and solve the system (5) for each group, in turn. If the machine is perfect and agrees with the model, there will be an unique solution for

$$\delta p/p\quad x'_1\ x'_2\ x'_3\ x'_4\ \ldots$$

Otherwise, if one obtains different values when calculated in two different groups, it means that inside either group something is wrong, like a localized unexpected kick or an erroneous reading in a monitor. In the former case, to represent the machine with Eq.(4), the appropriate correction should be found and inserted in the transfer matrices.

The procedure can be extended to analyze other locations in the machine, that we label with the index *m*, other than BPM's. Once angles and momentum offset are established for a group of three monitors, using the transfer matrix between any one of them and *m*, one can predict position and angle

$$x_m\ x'_m$$

at the new location. If at *m* there is no monitor, we will not know whether these values reflect the reality, but we know that, if at *m* there is anything unpredicted with the machine (or the model), the above quantities calculated from different groups of BPM's will be different. In particular, they will be different if calculated by the same group by a clockwise or counter-clockwise transformation along the machine.

It is easy to recognize if the error is due to a kick or to a monitor misreading. In the former case, there will be a different result when the calculation is performed with two groups of three that have an *interval* in common, and then we will search for the kick in that interval. In the latter case, the result will be different if calculated with two groups that have a *monitor* in common.

The eventual kick $\delta x'$ can be found in the following way. As a specific example, assume that results at *m* due to groups

* Work supported by the U.S .Department of Energy.

(1,2,3), (2,3,4), (3,4,5) and then (6,7,8), (7,8,9) give the same result at m, while groups (4,5,6) and (5,6,7) give a different result. This may mean that there is an unknown kick between BPM's 4 and 5, since the latter two groups have this interval in common.

Now, since a *partial* solution of Eq.(5) can be written as follows

$$\begin{pmatrix} x'_u \\ x'_v \\ \delta p/p \end{pmatrix} = \mathbf{P}^{(j)} \begin{pmatrix} x_i \\ x_j \\ x_k \end{pmatrix} \qquad (8)$$

with the indices u and v being any two of i, j, k. The elements of **P** for a "good" triplet must be identical with the ones for a "bad" triplet, corresponding to the *same* data x. These elements can be expressed, after inverting the matrix in Eq.(5), in terms of the Twiss functions and, for the "bad" **P**'s, must contain the unknown kick. Finally, a system of equations is obtained (that we omit here for lack of space), that explicitly yields the kick, position and strength, in terms of the model (Twiss functions) and the measured BPM data.

Another approach, convenient with fast workstations, is to fit the analysis of the measured data with an iterative series of MAD runs, containing varied kicks and/or simulated monitor reading errors. The results presented in the next section rather reflect this methodology.

III. RESULTS

Fig.1 represents the analysis of difference orbits in the AGS Booster measured at 22 BPM's (two are physically missing), with an horizontal kick of about 2 mrad given to the beam in a position between BPM's E4 and E6, actually very close to E6. We have plotted the resulting momentum offset and the position and angle at BPM C2 as a function of the data triplet used, referred for convenience to the position of the central BPM of the triplet.. The curves show a sharp bump in the E4-E6-E8 region.

We have somewhat reproduced the results with MAD (Fig.2), applied a 2 mrad kick in the same location.

Fig.3 and 4 represent the analysis of orbit data with a forced momentum offset of $\pm$ 1.5 10^{-3}.

Finally, we mention that a similar analysis performed on the bare orbit during the 1992 operating year of the machine showed possible errors in the F6-region. A subsequent survey confirmed magnet misalignment there and ring inspection found an erroneous electrical connection in the coils wrapped around the vacuum chamber that are used to correct for eddy current multipoles.

IV. REFERENCES

[1] Ch.Iselin, J.Niederer, CERN/LEP-TH/88-38, Geneva (1988).

[2] A.Luccio, "Algorithms and Modelling for the AGS Booster", *Nucl. Inst. & Meth* **A293**, p.460 (1990)

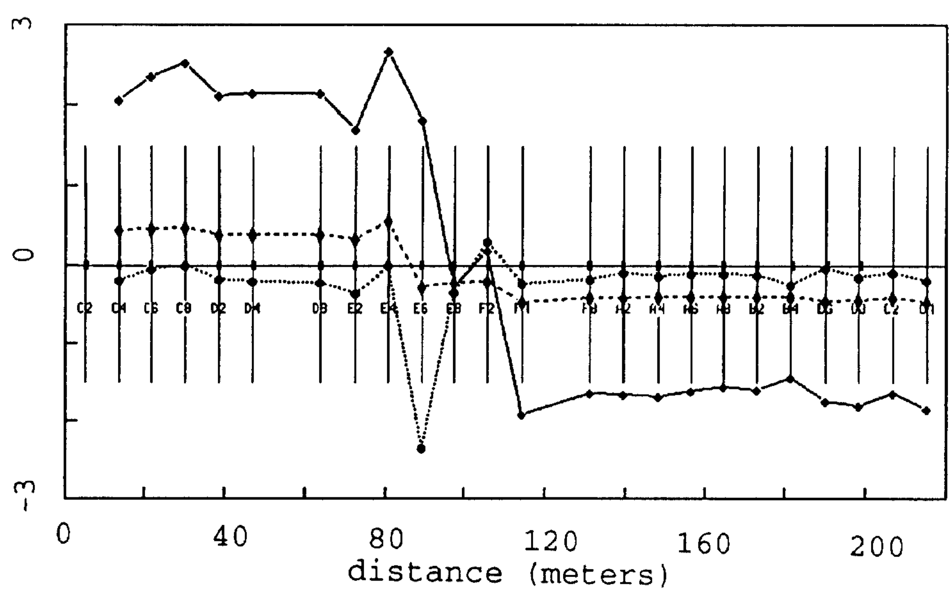

Fig.1. Analysis of difference orbits in the AGS Booster with a kick of 2 mrad applied at location E6. Data calculated at C2 from successive BPM triplet data. The solid curve represents x [mm], the dashed curve x' [mrad] and the dotted curve dp/p [10^{-3}].

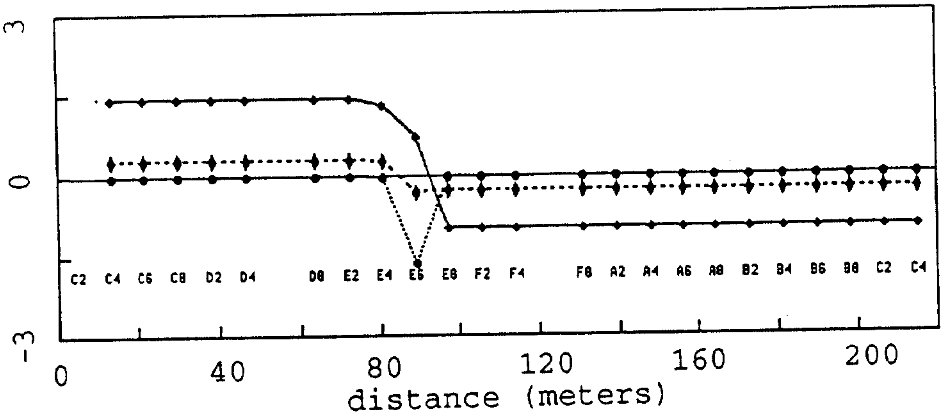

Fig.2. MAD simulation of the effect on the orbit by a 2 mrad kick localized at E6. Same conventions as in Fig.1.

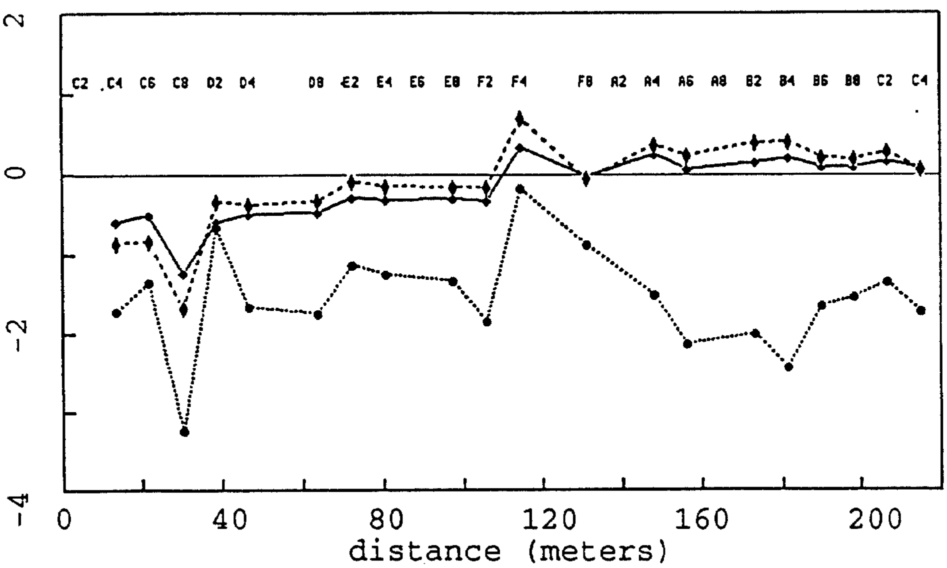

Fig.3. Analysis of difference orbits when the beam momentum was offset by -1.5 10^{-3}.

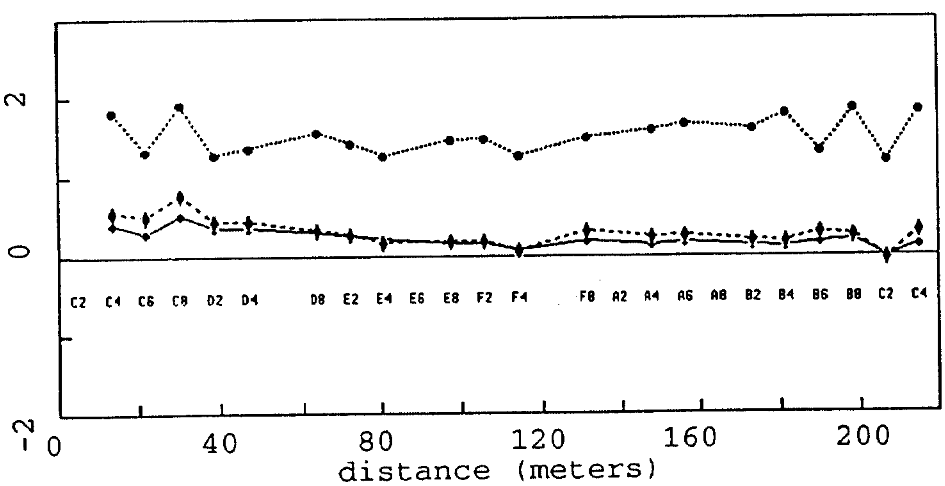

Fig.4. Analysis of difference orbits when the beam momentum was offset by +1.5 10^{-3}.