A TOOL FOR MODEL BASED DIAGNOSTICS OF THE AGS BOOSTER

Alfredo Luccio
AGS Dept., Brookhaven National Laboratory
Upton, NY 11973-5000

MAR 30 1994

OSTI

ABSTRACT

A model-based algorithmic tool was developed to search for lattice errors by a systematic analysis of orbit data in the AGS Booster synchrotron. The algorithm employs transfer matrices calculated with MAD¹ between points in the ring. Iterative model fitting of the data allows one to find and eventually correct magnet displacements and angles or field errors.

The tool, implemented on a HP-Apollo workstation system, has proved very general and of immediate physical interpretation.

INTRODUCTION

For this work we had a specific motivation. The Booster synchrotron makes use of orbit bumps for injection, extraction, and so on. Magnet currents for the bumps are calculated according to the model of the machine lattice, as a part of the model based control system of the machine². A satisfactory calibration of the bumps requires a good knowledge of the pre-bump orbit, position and angles, and of the momentum error of the beam. Accordingly, a procedure was developed to obtain these information from a comparison of a measured distorted orbit with the predictions of the model.

A more general motivation was a consequence. The algorithms developed to help solve the specific bump problem are of wider use. Indeed, they have evolved into a general computer tool to systematically search for errors in the machine lattice and suggest corrections. Moreover, they have helped to improve the agreement between the real accelerator and its model.

One starts with a systematic set of experimental data of orbit readings at the beam position monitors (BPM's), under a variety of circumstances. Then, transfer matrices are calculated with the model between pairs of locations in the accelerator lattice: BPM's, bump magnets, and other positions of interest for a specific task. The procedure then solves a variety of problems using both sets: the experimental data and the model parameters.

THEORETICAL BASIS

Without lack of generality, consider only the motion in one plane, say, the horizontal. Read the beam position at three BPM's

$$(x_i, x_j, x_k). \quad (1)$$

Calculate with MAD dispersions and their derivatives at these locations

$$(\eta_i, \eta_j, \eta_k), (\eta'_i, \eta'_j, \eta'_k). \quad (2)$$

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

5000709

The transfer between BPM i and j can be represented by the equation

$$\begin{bmatrix} x \\ x' \end{bmatrix} - \frac{\delta p}{p} \begin{bmatrix} \eta \\ \eta' \end{bmatrix} = \mathbf{M}^{(i,j)} \begin{bmatrix} x \\ x' \end{bmatrix} - \frac{\delta p}{p} \begin{bmatrix} \eta \\ \eta' \end{bmatrix} \quad (3)$$

where x'_i is the (unknown) angle of the orbit at location i and $\delta p/p$ the (unknown) beam momentum offset. The transfer matrices are

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

with

$$\begin{aligned} A &= \sqrt{\frac{\beta_j}{\beta_i}} [\cos \Delta\phi + \alpha_i \sin \Delta\phi] & B &= \sqrt{\beta_j \beta_i} \sin \Delta\phi \\ C &= -\frac{1}{\sqrt{\beta_j \beta_i}} [(\alpha_j - \alpha_i) + (1 + \alpha_i \alpha_j) \sin \Delta\phi] & D &= \sqrt{\frac{\beta_i}{\beta_j}} [\cos \Delta\phi - \alpha_j \sin \Delta\phi] \end{aligned} \quad (5)$$

α and β are lattice Twiss functions, and $\Delta\phi = \phi_j - \phi_i$ the phase difference between two locations.

Eq. (3) explicitly produces a system of 4 equations in the 4 unknown quantities

$$(x'_i, x'_j, x'_k; \delta p/p),$$

i.e.

$$\begin{cases} C^{(i,j)} x_i = x'_j - D^{(i,j)} x'_i + F^{(i,j)} \delta p/p \\ C^{(j,k)} x_j = x'_k - D^{(j,k)} x'_j + F^{(j,k)} \delta p/p \\ x_j - A^{(i,j)} x_i = B^{(i,j)} x'_i + E^{(i,j)} \delta p/p \\ x_k - A^{(j,k)} x_j = B^{(j,k)} x'_j + E^{(j,k)} \delta p/p \end{cases}, \quad (6)$$

with coefficients

$$\begin{aligned} E^{(i,j)} &= \eta_j - A^{(i,j)} \eta_i - B^{(i,j)} \eta'_i \\ F^{(i,j)} &= -\eta'_j + C^{(i,j)} \eta_i + D^{(i,j)} \eta'_i \end{aligned} \quad (7)$$

Let us now visit all BPM's around the accelerator in groups of three

$$1,2,3 \quad 2,3,4 \quad 3,4,5 \quad \dots\dots$$

and solve the system (5) for each group, in turn.

Only if the machine is perfect and agrees with the model, there will be an unique solution for the angles and momentum offset, when calculated in each group

$$x'_1, x'_2, x'_3, x'_4, \dots, \delta p/p.$$

If this does not happen, the next task -to address the general case as spelled out in the Introduction- is to find the source of errors within a group, like a localized unexpected kick or an erroneous reading in a monitor.

ANALYSIS OF ERRORS

A first observation is that, in principle, one could use the procedure described in the previous section by choosing *any* groups of three BPM's -not necessarily consecutive- A second, is that the solution to be examined doesn't necessarily belong to a BPM, but can be taken at any location in the machine (index m) -e.g. the desired location of an orbit bump. In this case, if at m there is no monitor, also the position x is part of the calculated data.

Many strategies are possible. For instance, let us take *two* consecutive groups of three consecutive monitors and calculate $\delta p/p$ and orbit position and angle at m and suppose that the results are different. Two cases are particularly interesting: the two groups have (a) an *interval* in common, or (b) an *element* (BPM) in common. In case (a) we will naturally look for an error in the interval, e.g. a magnet misalignment or field error, that can be represented by a kick; in case (b) we will expect to find an erroneous reading of that BPM

Another game is also interesting. Let us calculate $\delta p/p$, x and x' at m from the same group twice, once clockwise around the ring and then counter clockwise. If one of the results differ from what the other groups on the average say, we know on what part of the machine the error should reside

To give a feeling of how the tool works, let us examine in some detail an hypothetical case where a group, A, is giving at m a "good" result -i.e. a result that reasonably agrees with the majority- and two groups, B and C, with an interval in common, give "bad" results at m . A is made of monitors (1,2,3), B of (2,3,4), and C of (3,4,5). According to our previous discussion, we will naturally look for an unknown kick in the interval (3,4). Of this kick, we want to determine position and strength.

Let us represent the kick with a matrix **K**. It is easy to show that the solution at m can be written as follows

$$\begin{pmatrix} x \\ x' \\ \frac{\delta p}{p} \end{pmatrix}_m^{\text{"bad"}} = \mathbf{M}^{(2,m)} \begin{pmatrix} x \\ x' \\ \frac{\delta p}{p} \end{pmatrix}_2 + \mathbf{M}^{(3,m)} \mathbf{K}, \quad (8)$$

where **M** is the MAD-known transfer matrix. Since the "good" solution is given by the leftmost part of Eq. (8), i.e.

$$\begin{pmatrix} x \\ x' \\ \frac{\delta p}{p} \end{pmatrix}_m = M^{(2,m)} \begin{pmatrix} x \\ x' \\ \frac{\delta p}{p} \end{pmatrix}_2, \quad (9)$$

the elements of $\mathbf{K}$ satisfy the following equation

$$\mathbf{K} = (\mathbf{M}^{(3,m)})^{-1} \begin{pmatrix} \Delta x \\ \Delta x' \\ \Delta \frac{\delta p}{p} \end{pmatrix}_m, \quad (10)$$

where the Δ 's denote differences between "bad" and "good" values.

Since we need four parameters to completely determine $\mathbf{K}$: three independent matrix elements and a kick strength, to solve our problem, we must write Eq. (10) twice, using both bad guys B and C.

Very often, we found however more convenient, working with fast workstations, to use a trial- and -error approach and directly match the measured data with the model using an iterative series of MAD runs, containing varied kicks and/or simulated monitor reading errors. The results presented here rather reflect this latter strategy.

RESULTS

Some results are summarized in the figures.

An horizontal kick of about 2 mrad was applied between BPM's E4 and E6 in the AGS Booster. The difference orbit measured at 22 BPM's was analyzed, with the results shown in figure 1. The figure shows a plot of the calculated momentum offset and of the position and angle at BPM C2 as a function of the data triplet used. In the figure, the horizontal coordinate is the position of the central BPM of the triplet. The curves show a sharp bump in the E4-E6-E8 region.

The case shown in figure 1 was simulated and somewhat reproduced with MAD, with a kick inserted in the same location. The results are shown in figure 2.

To test the capability of the algorithm to calculate the beam momentum offset, the moment was forced off by $\pm 1.5 \cdot 10^{-3}$ and a series of difference orbits were analyzed. The results -quite satisfactory- are shown in the figures 3 and 4.

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.

CONCLUSIONS

The algorithm has proved useful to calculate machine and beam parameters prior to the application of an orbit bump. It has also shown capabilities of analyzing lattice errors and suggest corrections. Finally, it has developed into a general tool to improve our knowledge of the machine and the consistency between the real accelerator and its computer model.

ACKNOWLEDGEMENTS

Discussions with E. Auerbach and J.Niederer are gratefully acknowledged.

REFERENCES

1. Ch.Iselin, J.Niederer, The MAD Program, version 7.2. 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. Results for a kick of 2 mrad in the AGS Booster (x , solid curve; x' , dashed curve; $\delta p/p$, dotted curve).

Fig. 2. Simulation with MAD of the case shown in Fig. 1.

Fig. 3. Analysis of difference orbit with $\frac{\delta p}{p} = +0.15\%$.

Fig. 4. Analysis of difference orbit with $\frac{\delta p}{p} = -0.15\%$.

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.