BNL-101504-2014-TECH

AD/AP 14;BNL-101504-2013-IR

Analysis of effects of closed orbit errors, quadrupole: Random errors and random quadrupole rotation errors for the SSC LEB

J. Milutinovic

November 1989

Collider Accelerator Department

Brookhaven National Laboratory

U.S. Department of Energy

USDOE Office of Science (SC)

DISCLAIMER

AD/AP/TN-14

Accelerator Development Department
Accelerator Physics Division
BROOKHAVEN NATIONAL LABORATORY
Associated Universities, Inc.
Upton, NY 11973

Accelerator Physics Technical Note No. 14

Analysis of Effects of Closed Orbit Errors, Quadrupole $\Delta K/K$ Random Errors and Random Quadrupole Rotation Errors for the SSC LEB

J. Milutinovic and A.G. Ruggiero

November 1989

ANALYSIS OF EFFECTS OF CLOSED ORBIT ERRORS, QUADRUPOLE ΔK/K RANDOM ERRORS AND RANDOM QUADRUPOLE ROTATION ERRORS FOR THE SSC LEB

J. Milutinovic and A.G. Ruggiero

Abstract

We have examined the impact of several types of magnet imperfections in the SSC LEB, on the closed orbit and linear optics characteristics of the machine. We have found out that, at the general rms error level of 3×10^{-4} (1×10^{-3} for ΔK/K) in the appropriate units, either the consequences are harmless or they can be successfully dealt with by engaging a Fermilab type three bump correction scheme. For the latter to be effective, a BPM and a dipole corrector have to be installed beside each quadrupole, where the appropriate beta function is large, and the maximum integrated kick strength of 160 G.m is needed at the top magnetic rigidity $B\rho = 41$ T.m.

Introduction

An accelerator lattice cannot be expected to be perfect and as an immediate consequence the same will be true for its linear optics properties and closed orbit.[1] Since more or less reliable assumptions can be made about realistic lattice errors, it is important to see how they translate into expected closed orbit distortions and linear optics shifts, and if these effects exceed acceptable values to see how to correct them.

Among many possible sources of orbit distortions, we have selected four major types of lattice errors. They are the error in the integrated dipole field strength $\Delta(B\ell)/B\ell$, the axial tilt of the dipole $\Delta\theta$, and the lateral displacements of the quadrupole along the two transverse directions.

The rms values of the lattice errors we have used are the following ones:

$\Delta(B\ell)/B\ell = 0.3 \times 10^{-3}$, $\Delta\theta = 0.3 \times 10^{-3}$ radians,

Lateral quad displacements $\Delta_Q X = \Delta_Q Y = 0.3 \times 10^{-3}$ m.

The rms values we selected were typical values that we previously found acceptable for the AGS Booster, even though we knew in advance that the SSC LEB is a "tougher", i.e. a more error sensitive machine.

In the presence of sextupoles and other nonlinearities, such closed orbit distortions, if left uncorrected, cause changes in linear optics properties of the machine such as beta variations and tune shifts. However, there are also other lattice errors that affect linear optics properties, even though they do not directly cause orbit distortions. We have selected two of them for examination. First error is quadrupole gradient random error $\Delta K/K$, while the second one is quadrupole random rotation $\Delta\theta_Q$. The latter error will cause the appearance of a skew quadrupole component, proportional to the small $\Delta\theta_Q$ angle, and this will introduce coupling between horizontal and vertical degrees of freedom. We have selected the following rms values for these two effects:

$$\Delta K/K = 10^{-3} , \qquad \Delta\theta_Q = 0.3 \text{ milliradians.}$$

A 2.5σ cut was imposed on all distributions of random errors used in the simulation of the previously mentioned effects.

The tracking/analysis code PATRIS was used to handle the simulation and analysis of closed orbit distortions and furthermore to correct them. However, no attempt was made to introduce correction to offset $\Delta K/K$ effects or to reduce coupling caused by random quadrupole rotations.

The Results or Realistic Closed Orbit Modeling and Corrective Actions

Here we will briefly describe the results of closed orbit modeling. Many details of how the problem is simulated and how the orbit is corrected were discussed in our previous technical notes[2,3,4] and will not be repeated here.

With the adopted rms error values, we tested the lattice for 10 different sequences of random errors. The results can be roughly divided into two groups. The first group consists of seven distributions of random lattice errors that can be all called "favorable distributions." This is because the three bump correcting scheme was capable of reducing the closed orbit distortions to less than a millimeter in both planes. In all these cases the first correction, performed with sextupoles on, was not enough, but the second iteration clearly sufficed. Maximum kick angles in each random number distribution encountered in this group of results were at least 0.3 mrad, the absolute maximum among the seven cases was $\theta = 0.3885$ mrad. At the top magnetic rigidity of 41 T.m this translates into the integrated kick strength $\delta(B\ell)_{max} = 160$ G.m.

The fact that the second iteration was more than sufficient also indicated that the iterative scheme converged well in all these cases. Also, the corrected lattices displayed much smaller shifts in linear optics functions, the largest tune shift in the whole group dropped from 0.02 to 0.0028. In most cases, however, the results were much better.

The second group consisted of three distributions which can be called "unfavorable." This is because the code could not make the first turn around with the sextupoles being turned on. In one case that we analyzed in more detail, it was obvious that the uncorrected lattice was in the close proximity of an integer tune in the horizontal plane. This happened because the sextupoles, crossed by the distorted closed orbit, created tune shifts which brought the lattice to that undesirable tune value. To handle such kinds of situations, we turned the sextupoles off, then corrected the orbit and recorded the corrective kick strengths for this case. Then we simultaneously turned the sextupoles and the correctors on and started with a sort of "precorrected" orbit. This precorrection was more than sufficient; the orbit distortions to start with, in the presence of energized sextupoles, were significantly below 0.01 mm on all monitors/correctors and no further correction was necessary. This proves once again that trying to establish the first turn around with sextupoles off is indeed a good strategy. The maximum integrated kick strength in this case was $\delta(B\ell)_{max} = 135$ G.m, at the top magnetic rigidity $B\rho = 41$ T.m.

The conclusion of this section is that the Fermilab style three bump method can handle the problem of closed orbit distortions even in more difficult cases. In such difficult cases, one has to try to establish and precorrect the orbit with sextupoles off. In any case, this seems to have been a good strategy on any machine we have handled so far.

Here we would add one final remark. A possibility that this lattice might be fairly sensitive to any kind of systematic quadrupole displacements was presented to us.[5] To check any adverse consequence, we modified PATRIS to make possible this kind of simulation. With a systematic quadrupole shift of 0.3 mm we did not see any problems with sextupoles on; just one iteration was more than enough to correct the orbit. The maximum integrated kick strength was in this case $\delta(B\ell)_{max} = 21$ G.m at the top energy.

The Effects of Quadrupole Gradient Random Errors

We assumed the rms value of $\Delta K/K$ to be 1×10^{-3}. Each quadrupole gradient received a random perturbation with the rms value given above, with the usual 2.5σ cut, while the remaining components of the lattice were assumed to be ideal, i.e. at their exact design values. Three different distributions of random errors were tried and examined. We were interested in the changes of linear optics characteristics of the lattice as a result of these perturbations. These changes turned out to be small in all of the cases we examined.

The maximum tune shift encountered in these three runs was

$$\Delta\nu_{max} = 0.0064 \quad .$$

For the three $\Delta K/K$ random error distributions we employed, the maximum relative variations of beta and eta functions, at one fixed location, in the middle of a horizontally focusing quadrupole, were as follows

$$(\Delta\beta_H/\beta_H) = 0.010 \ , \ (\Delta\beta_v/\beta_v) = 0.026 \ , \ (\Delta\eta_H/\eta_H) = 0.010 \quad .$$

On the basis of the foregoing, we have concluded that no correction will be necessary to handle these effects.

The Effects of Random Rotation of the Quadrupole

We performed a series of computer simulations under the assumption that all quadrupoles are rotated about their axis in a random manner, with $\theta_{rms} = 0.3$ mrad and 2.5σ cut, and with the remaining lattice parameters kept unchanged, i.e. at their ideal design values. As in the case of quadrupole gradient random errors, three different distributions of random numbers were used here. We wanted to examine some of the consequences of the coupling between the two transverse planes introduced in this way. The amount of coupling turned out to be fairly small. The diagonal elements of the total transfer matrix did not display any changes within the adopted printout accuracy (3 significant digits in E–format), whereas the off–diagonal elements changed by various amounts ranging from 10^{-6} in A_{23} to 10^{-3} in A_{14}, for example.

The maximum shifts in linear optics functions that we found were

$$\Delta\beta_H = 0.000015m \quad , \quad \Delta\beta_v = 0.000002m$$

$$\Delta\eta_H = 0.000001m \quad , \quad \Delta\eta_v = 0.000262m$$

while the tune shifts were below what is normally printed out, i.e. below 10^{-6}!

Therefore, we conclude that the coupling caused by random quadrupole rotations should not present any problems.

References

1. E. Courant & H. Snyder, Annals of Physics 3, 1 (1958).
2. J. Milutinovic & A. G. Ruggiero, Closed Orbit Analysis for the AGS Booster, Booster Technical Note No. 107, and references cited therein.
3. J. Milutinovic & A. G. Ruggiero, Closed Orbit Analysis for RHIC, Technical Note AD/RHIC–AP–78.
4. J. Milutinovic & A. G. Ruggiero, Effects of Quadrupole Gradient Errors in the AGS Booster, Booster Technical Note No. 112.
5. S. Tepikian, private communication.