EFFECTS OF CONSTRUCTION AND ALIGNMENT ERRORS ON THE ORBIT FUNCTIONS OF THE ADVANCED PHOTON SOURCE STORAGE RING

H. Bizek, E. Crosbie, E. Lessner,
L. Teng, and J. Wirsbinski
Argonne National Laboratory
Advanced Photon Source
9700 South Cass Avenue
Argonne, IL 60439

Abstract

The orbit functions for the Advanced Photon Source Storage Ring have been studied using the simulation code RACETRACK. Non-linear elements are substituted into the storage ring lattice to simulate the effects of construction and alignment errors in the quadrupole, dipole, and sextupole magnets. The effects of these errors on the orbit distortion, dispersion, and beta functions are then graphically analyzed to show the rms spread of the functions across several machines. The studies show that the most significant error is displacement of the quadrupole magnets. Further studies using a 3 bump correction routine show that these errors can be corrected to acceptable levels.

I. INTRODUCTION

The Advanced Photon Source (APS) will be a third generation, 7-GeV synchrotron radiation source. The storage ring will contain 80 dipole bending magnets and 400 focusing quadrupole magnets in a Chasman-Green type lattice. It will also contain 120 chromaticity sextupoles, 160 harmonic sextupoles, and 40 dispersion free straight sections for a total circumference of 1104 m. Figure 1 shows where these components, as well as the beam position monitors and orbit correcting magnets are located in the storage ring lattice.

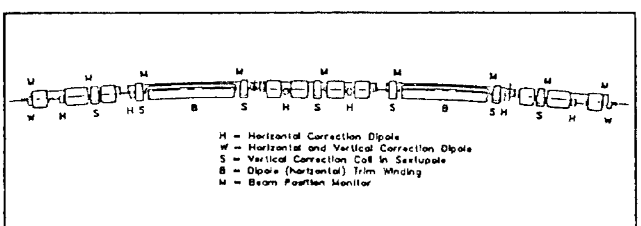

Figure 1: APS Storage Ring Cell Without Straight Sections

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Errors in the construction and alignment of the magnets adversely affect the orbit functions of the storage ring. These effects are computed and studied in order to set tolerances for the construction and installation of the magnets.

The orbit simulation code RACETRACK with Orbit Corrections was used. RACETRACK with Orbit Corrections is a version of the program RACETRACK, modified by Hiroshi Nishimura and Albin Wrulich [1] to include orbit corrections. Both programs track transverse nonlinear particle motion in accelerators; multipoles up to 20-pole are included and treated as thin elements.

In addition, once a stable closed orbit is established, RACETRACK with Orbit Corrections has the ability to correct orbit distortions using the correcting dipoles. It accomplishes this reduction using a local three dipole bump correcting routine.

II. PROCEDURE

The following steps were followed to conduct the study of the orbit functions:

1. An error type and level was chosen.
2. Generally 10 different random seeds were run for each error level to generate 10 different random distributions of errors.
3. The values, both horizontal and vertical, of the beta functions, orbit distortion and dispersion were then graphed using the spreadsheet 2020.
4. For the quadrupole misalignments, 22 seeds were run and the correction routine was activated to verify that the effects of this error could be reduced to within acceptable values.

III. RESULTS

Of all the errors studied, the one that produced the greatest orbit distortion was the transverse misalignment of the quadrupole magnets. The distorted orbits, the beta functions, and the dispersion functions are shown in Figures 2, 3, and 4 for an rms quadrupole misalignment of 0.1 mm.

Orbit correction was studied with RACETRACK with Orbit Corrections. After correction, the spread of the distortions of the orbit, the beta functions, and the dispersion functions were greatly reduced as shown in Figures 5, 6, and 7.

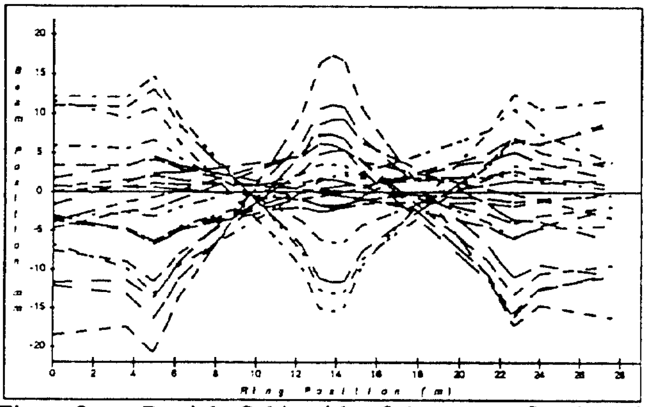

Figure 2: Particle Orbit with a 0.1 mm rms Quadrupole Misalignment

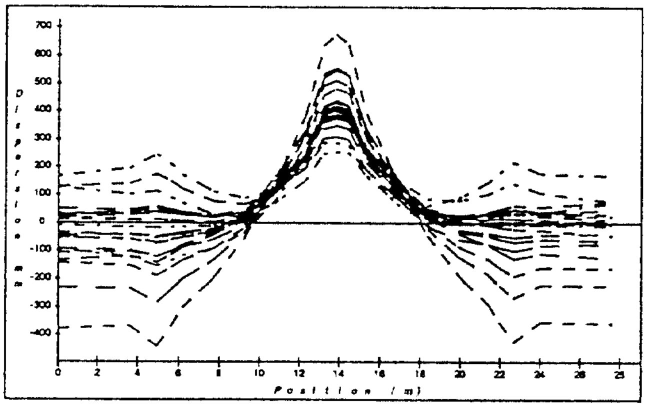

Figure 3: Horizontal Dispersion with a 0.1 mm rms Quadrupole Misalignment

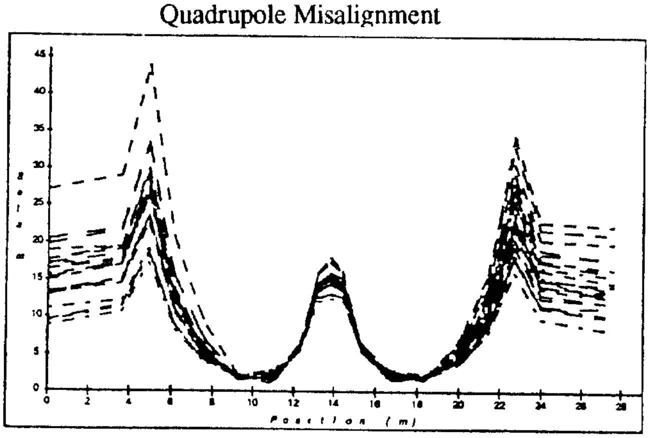

Figure 4: Horizontal Beta Functions with a 0.1 mm rms Quadrupole Misalignment

Random field errors in the dipole magnets (ΔB/B) did not have any effect on the vertical orbit distortion or the vertical dispersion. They did, however, distort the horizontal orbit and dispersion function, as well as both the horizontal and vertical beta functions.

The roll misalignment errors had minimal effect on the orbit functions. The three functions most distorted were the vertical orbit and the horizontal and vertical dispersion functions.

Transverse displacement of the sextupole magnets had no effect on the orbit and minimal effect on the dispersion. The distortion of the beta function is shown in Figure 8.

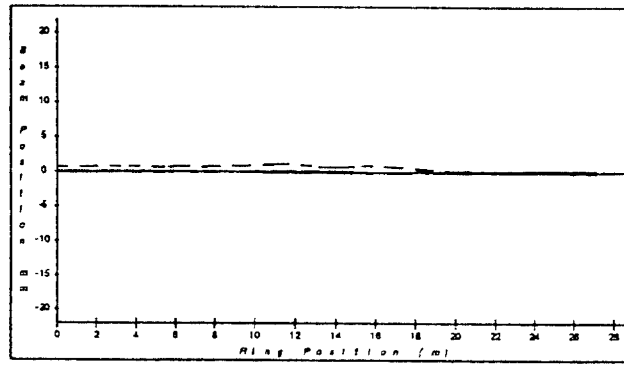

Figure 5: Particle Orbit after Correction of a 0.1 mm rms Quadrupole Misalignment

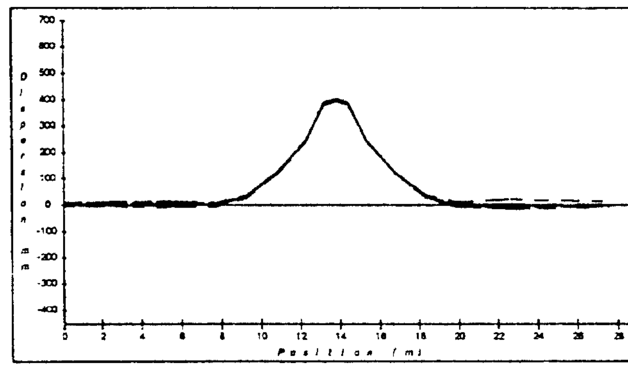

Figure 6: Horizontal Dispersion after Correction of a 0.1 mm rms Quadrupole Misalignment

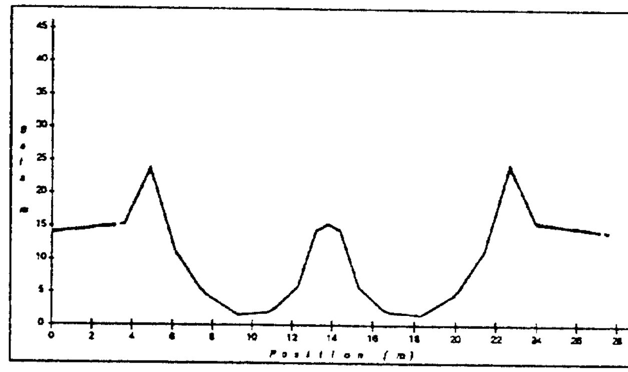

Figure 7: Horizontal Beta after Correction of a 0.1 mm rms Quadrupole Misalignment

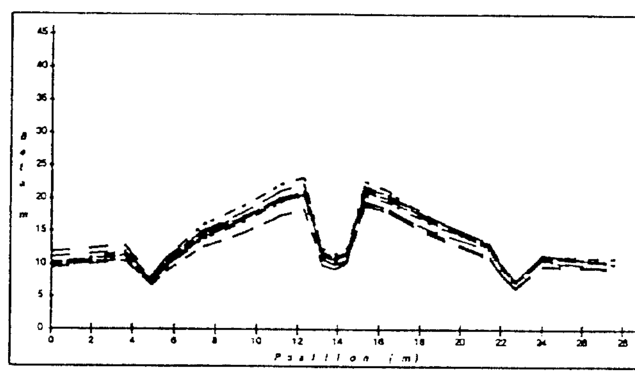

Figure 8: Vertical Beta Function with a 0.1 mm rms Displacement of the Sextupole Magnets.

The field gradient errors in the quadrupole magnets ($\Delta B'/B'$) distorted the beta functions and the horizontal dispersion, while the particle orbits and the vertical dispersion were unaffected. Figures 9 and 10 show the distortions of the dispersion and beta functions due to an rms error magnitude of 1%.

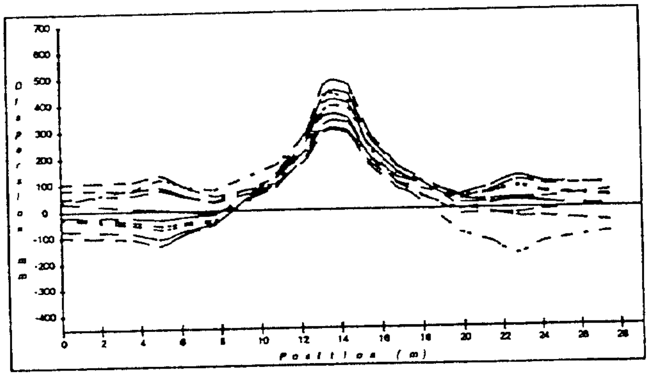

Figure 9: Horizontal Dispersion Function with a Gradient Field Error of 1% in the Quadrupole Magnets

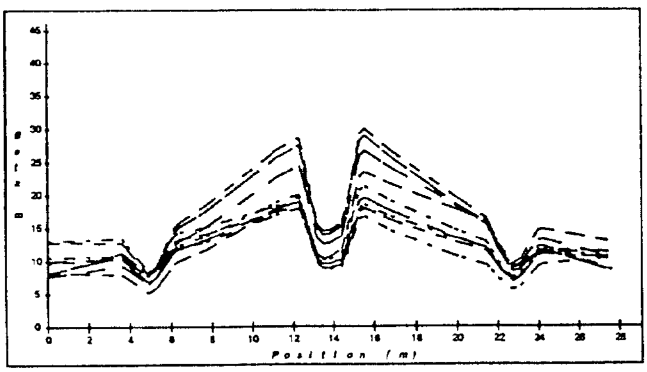

Figure 10: Vertical Beta Function with a Gradient Field Error of 1% in the Quadrupole Magnets

The distortions caused by the transverse misalignment of sextupoles and the quadrupole field gradient errors cannot be corrected using the local bump method found in RACETRACK with Orbit Corrections; however, these distortions can be minimized by tuning the quadrupole magnets.

For random errors the orbit function distortions can be evaluated analytically. These are

Orbit distortion

$$\frac{\delta z}{\sqrt{\beta}} = \frac{1}{2|\sin\pi\nu|} \begin{cases} \sqrt{\sum_{Q}\beta k^2}\;\Delta z_{qrms} \\ \sqrt{\sum_{D}\beta\Theta^2}\;\left[\left(\frac{\Delta B}{B}\right)_{rms} \text{ or } \phi_{rms}\right] \end{cases}$$

β-function distortion

$$\frac{\delta\beta}{\beta} = \frac{1}{2|\sin 2\pi\nu|} \begin{cases} \sqrt{\sum_{S}\beta^2 s^2}\;\Delta z_{srms} \\ \sqrt{\sum_{Q}\beta^2 k^2}\;\left(\frac{\Delta B'}{B'}\right)_{rms} \end{cases}$$

where $\Theta \equiv B\ell/B\rho$ = dipole strength, $k \equiv B'\ell/B\rho$ = quadrupole strength, $s \equiv B''\ell/B\rho$ = sextupole strength, ϕ ≡ dipole roll error, Δz_q ≡ quadrupole misalignment, Δz_s ≡ sextupole misalignment, and $\sum_D$, $\sum_Q$ and $\sum_S$ denote summations over all dipoles, quadrupoles and sextupoles respectively; and the formulas apply to both the horizontal ($z \rightarrow x$) and the vertical ($z \rightarrow y$) planes. In APS the numerical results are given in Table 1.

Table 1
Orbit and β-distortion due to various random errors derived analytically

Errors	Orbit distortion $\delta z/\sqrt{\beta}$	β-distortion $\delta\beta/\beta$
Δx_{qrms}=0.1 mm	0.00236 $m^{1/2}$	
Δy_{qrms}=0.1 mm	0.00167 $m^{1/2}$	
$\left(\frac{\Delta B}{B}\right)_{rms} = 10^{-2}$	0.00885 $m^{1/2}$	
$\phi_{rms}=10^{-2}$	0.0178 $m^{1/2}$	
Δx_{srms}=0.1 mm		0.0211
Δy_{srms} = 0.1 mm		0.0460
$\left(\frac{\Delta B'}{B'}\right)_{rms} = 10^{-2}$		0.00628

We see that the analytical results agree approximately with the numerical results.

IV. CONCLUSION

The results of this study show that the most severe effects on the orbit functions are caused by transverse misalignments of the quadrupole magnets, but they can be effectively corrected with the correction dipole system as designed.

V. REFERENCES

[1] "RACETRACK with Orbit-Corrections", H. Nishimura, A. Wrulich, 1986, private communication.