First Turn Beam Correction for the Advanced Photon Source Storage Ring*

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Abstract

A procedure was developed for precise realignment of the quadrupoles in a synchrotron radiation storage ring which can substantially ease the required precision of the initial survey. The procedure consists of first using the injected beam to obtain a closed orbit which is centered on the beam position monitors by the correction dipoles. The strengths of the correction dipoles then give the required fine-adjustment of the quadrupole positions. In this paper we discuss only the algorithm for obtaining the closed orbit.

I. INTRODUCTION

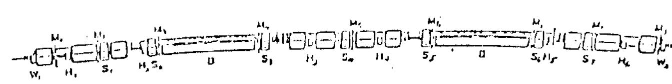
In the Advanced Photon Source (APS) the closed orbit distortion is mainly caused by misalignments of the quadrupoles. Because of the very strong focusing in the storage ring the amplification factor from quadrupole misalignment to orbit distortion is very large. The orbit distortion caused by a random transverse displacement δ of the quadrupoles is about 55 δ. The sextupole magnets in the ring are also very strong. Therefore, orbit distortions lead to large detunings, hence large reductions of the dynamic aperture [1]. An rms orbit distortion of about 5 mm causes a 50% reduction in dynamic aperture. If no orbit correction is applied this implies a tolerance in quadrupole misalignment of about 0.1 mm (rms). This tolerance is rather difficult to achieve with only survey techniques. The correction dipoles (correctors) are, therefore, added to the lattice to ease the survey tolerance.

The ring quadrupole alignment procedure is conceived to be of two stages. In stage one the ring is aligned by survey techniques to a high precision but not necessarily better than 100 μm. The correctors are then employed together with the beam position monitors (BPM) to steer an injected beam in a sequential procedure during the first turn to obtain a closed and corrected orbit. The distortion of the corrected orbit is limited by the resolution of the BPM readings for a single pass beam. Nevertheless, the distortion should be much better than the 5 mm tolerance required by the dynamic aperture consideration. One should be able to store a good beam on this orbit.

In stage two one uses the corrector settings to realign the quadrupoles. The strengths of the correction dipoles needed to produce the corrected orbit give direct information on the misalignment of individual quadrupoles. One can then move each individual quadrupole to correct its misalignment. The precision of this correction is limited by the accuracy with which the supporting mechanisms of quadrupoles can be adjusted. The accuracy of this adjustment is expected to be better than 20 μm. With the ring quadrupoles realigned to 20 μm one should attain an orbit distortion of some 1 mm with all correction dipoles now turned off. If desired the correctors can still be used to further correct the orbit or to stabilize the beam against vibrations through a feedback system to a precision of about 20 μm, the resolution of the BPM readings for a coasting beam.

II. ORBIT CORRECTION PROCEDURE

The APS storage ring consists of 40 Chasman-Green cells joined by long straight sections. In one cell there are 8 horizontal correctors, 9 vertical correctors and 9 BPMs each giving both horizontal and vertical readings. Their locations are shown in Fig. 1. Only seven pairs of correctors and BPMs are used in the simulation. All BPMs except the first and the last ones are located close to sextupoles. When the beam is centered in the BPM, it is then also centered in the sextupole. Hence, the BPM-centered orbit will suffer the least amount of detuning. The positions of the first and the last monitors in the cell have direct bearing on the position of the beam in the insertion device placed in the straight section.



H = Horizontal Correction Dipole
W = Combined Horizontal and Vertical Correction Dipole
S = Vertical Correction Coil in Sextupole
B = Dipole (horizontal) Trim Winding
M = Beam Position Monitor

Figure 1. One cell of the APS ring showing the locations of the correctors and BPMs

In this paper we explore a rather straightforward algorithm for setting the correctors in stage one. The procedure is the following:

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1) The quadrupoles are given a set of random Gaussian misalignments Δx_i and Δy_i with a prespecified variance.
2) The beam is injected at angle ϕ_1 through the center of BPM one (M1 of the first cell), tracked through a corrector (horizontal H1 in this case) to the following BPM, M2. In what follows we will only consider the horizontal plane as an example.
3) Corrector H1 is then adjusted to deflect the beam by an angle θ_1 to center it at M2. Even with sextupoles turned on, the dependence of the displacement at M2 on the deflection at H1 is linear enough to make linear interpolation quite good.
4) The corrected beam is tracked through the next corrector H2 to the following monitor M3. The deflection θ_2 at H_2 is then adjusted to center the beam at M3. This process continues all the way around until the last corrector is adjusted to center the beam back at M1.
5) The angle ϕ_2 of the beam at the start of the second turn at M1 will generally not be the same as ϕ_1. The injection angle ϕ_1 is then adjusted and the one-turn monitor-zeroing procedure repeated until $\phi_2 = \phi_1$. We now have a closed orbit which is centered at all monitors.

With a set of random misalignments of standard deviation 0.5 mm in quadrupoles, the uncorrected trajectory is shown in Fig. 2. The corrected closed orbit is shown in Fig. 3 and the required correction angles θ_i are plotted in Fig. 4. Figure 3 shows that the rms distortion of the corrected closed orbit is no more than 1 mm, well within the tolerance of 5 mm dictated by the dynamic aperture criterion.

III. REFINEMENTS, DISCUSSIONS AND CONCLUSIONS

Two refinements were also implemented:

1) The errors in the BPM reading and in the corrector setting can be simulated by adding a random displacement of specified variance to the zero value at the monitor after each step of correction. For the button type BPM and a single pass beam the appropriate variance is estimated to be about 200 μm. With these errors included the results are shown in Fig. 5 and 6.
2) When the required correction angle is larger than the maximum that can be provided by the corrector, the correction is set to the maximum value and proceeds to the next corrector. In this manner, initial quadrupole misalignments as large as 2 mm rms were shown to be correctable. The corrected orbit distortion has a variance of about 4 mm when the BPM resolution is again taken to be 0.2 mm.

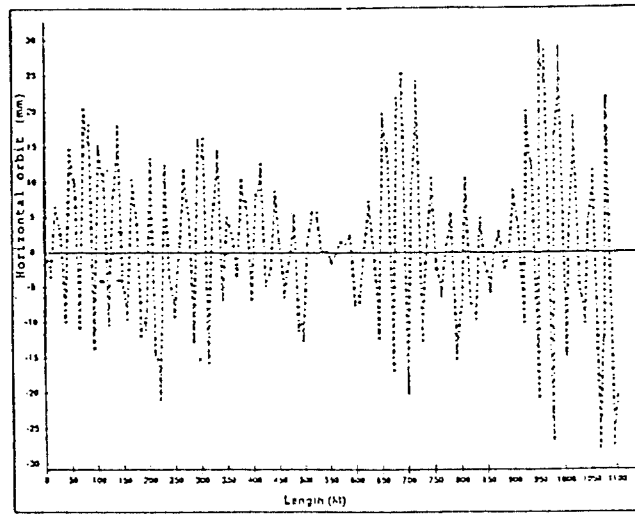

Figure 2. The uncorrected first turn beam with quadrupole misalignments $\Delta X_{qrms} = 0.5$ mm in horizontal plane.

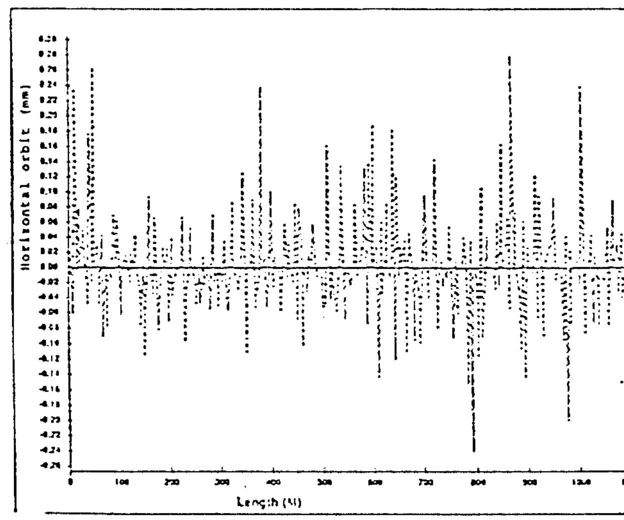

Figure 3. The horizontal closed orbit which is centered at all BPMs with quadrupole misalignments $\Delta X_{qrms} = 0.5$ mm

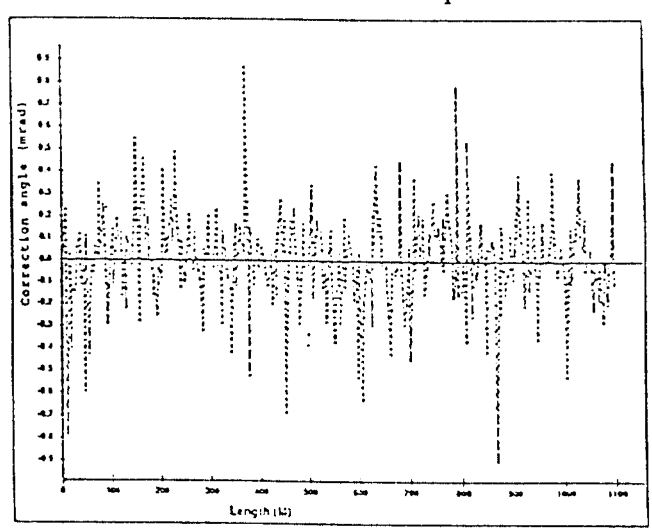

Figure 4. The required correction angles for quadrupole misalignments $\Delta X_{qrms} = 0.5$ mm

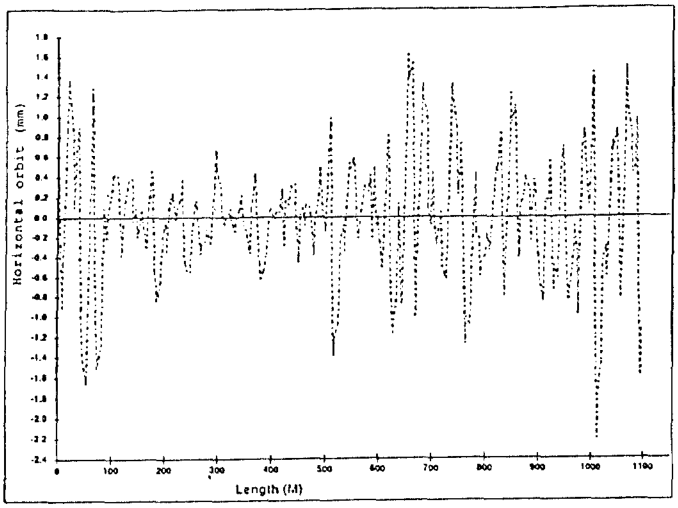

Figure 5. The horizontal closed orbit with quadrupole misalignments $\Delta X_{qrms} = 0.5$ mm and errors in BPM reading $\Delta X_{mrms} = 0.2$ mm

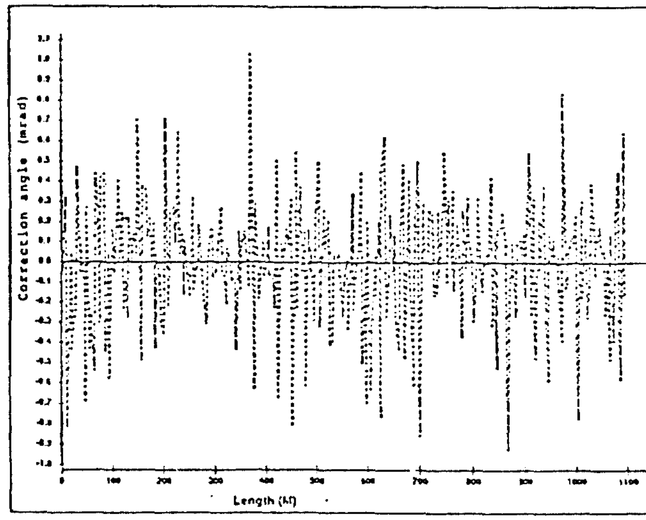

Figure 6. The required correction angles for the same case as in Figure 5

We conclude from these studies that a fine-realignment procedure as described, using the beam, the correctors and the beam position monitors as aids, can substantially ease the precision required of the initial alignment obtained only by surveying techniques. For the APS an initial survey alignment precision of 0.5 mm proves to be quite adequate.

IV. REFERENCES

[1] E. Lessner et al., "Effects of Errors on the Dynamic Aperture of the APS Storage Ring," Proceedings of this Conference.