CLOSED ORBIT ERRORS AND CORRECTION IN THE SXLS RING

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NATIONAL SYNCHROTRON LIGHT SOURCE

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1. Introduction

SXLS is an electron synchrotron/storage ring, used as an X-ray lithography source, with a critical wavelength of $\lambda=10$ A. It has a circumference of 8.5 m and its main elements are two 180° combined function dipole, four quadrupoles and two sextupoles. The horizontal and vertical tunes are 1.415 and 0.415, respectively.

The machine is being constructed in two phases. In Phase-1 and 2 it will run at 200 and 696 Mev using conventional (warm) and superconducting bending magnets, respectively. All other elements, as well as the lattice functions will be the same in the two phases.

The constraint that the exit slits impose on the photon beamlines, requires that the source point, that is the closed orbit be controlled to better than ± 3 mm horizontally, ± 2 mm and ± 1 mrad vertically. The following is a study of the expected closed orbit distortion in the ring as well as of the orbit monitor/corrector schemes necessary to correct the orbit.

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2. Sources of closed orbit errors

A single point kick of strength, Ψ , at $s = s_o$ along the circumference of a storage ring gives rise to a closed orbit displacement at position s ,

$$\zeta(s) = \frac{\Psi}{2} \sqrt{\beta(s_o)\beta(s)} \frac{\cos[\Delta\phi(s) - \pi\nu]}{\sin\pi\nu}, \quad \zeta = x_{co} \text{ or } y_{co}. \quad (1)$$

where $\beta(s_o)$ and $\beta(s)$ are the betatron functions at the location of the kick and the observation point respectively, $\Delta\phi(s)$ is the phase advance from the kick to the observation point and ν is the betatron tune. The angular deviation is obtained simply by differentiation,

$$\zeta'(s) = \frac{\Psi}{2} \sqrt{\frac{\beta(0)}{\beta(s)}} \frac{\sin[\phi(s) - \pi\nu] - \alpha(s)\cos[\phi(s) - \pi\nu]}{\sin\pi\nu}, \quad \alpha(s) = -\beta'(s)/2.$$

The point kicks are calculated from the field error, ΔB , the extent of the field error (length of the element where the error occur), L , and the beam rigidity, $B\rho$ as

$$\Psi_{x,y} = \frac{\Delta B_{y,x} L}{B\rho}. \quad (2)$$

If the phase advance along the kick is not small, the closed orbit must be determined from the more general equation for an extended kick,

$$\zeta(s) = \frac{\sqrt{\beta(s)}}{2\sin\pi\nu} \int_C \Psi(s') \sqrt{\beta(s')} \cos[\phi(s) - \phi(s') - \pi\nu] ds'.$$

It can be shown [1] however, that a uniform extended kick between points s_1 and s_2 ,

$$\Psi(s) = \begin{cases} \Psi_o = \frac{\Delta B}{B\rho} & s_1 < s < s_2 \\ 0 & \text{otherwise} \end{cases} \quad (3)$$

can be approximated with a point kick (equ(1)) using $\Psi = \Psi_o$, $\beta(s_o) = \beta_o$ and $\phi(s_o) = \phi_o$ given by the following expressions:

$$\tan\phi_o = \frac{\sqrt{\beta_1}\sin\phi_1 + \sqrt{\beta_2}\sin\phi_2}{\sqrt{\beta_1}\cos\phi_1 + \sqrt{\beta_2}\cos\phi_2}, \quad \beta_o = \frac{\tan^2 \frac{KL}{2}}{(KL)^2} [\beta_1 + \beta_2 + 2\sqrt{\beta_1\beta_2}\cos\Delta\phi].$$

In the XLS ring, the quadrupoles can be assumed to be the source of point kicks ($\Delta\phi_x = 3.9^\circ$ and $\Delta\phi_y = 5.4^\circ$) but errors in the dipoles should be treated as extended kicks, at least in the horizontal plane ($\Delta\phi_x = 170^\circ$ & $\Delta\phi_y = 18^\circ$).

In addition to actual field errors (ΔB , $\Delta B'$, $\Delta B''$, ...) in the magnets, field error, thus kick can arise from misalignment of dipoles, quadrupoles and sextupoles. Table-1 lists the field errors and their sources which can lead to closed orbit errors.

1. S.Krinsky: Closed orbit distortion resulting from an extended kick, NLSL Tech. Note #14, 1978.

Table-1
Sources of closed orbit errors

elmt	source	ΔB	$\Psi_{x,y}$	effect
pure	field error, ΔB_y	ΔB_y	$\Phi_b \Delta B_y / B_y$	x_{co}
	field error, ΔB_x	ΔB_x	$\Phi_b \Delta B_x / B_y$	y_{co}
D	displacement, Δz	$\Delta B_y = -B_y \Delta z$	$\Delta z / \rho$	x_{co}
I	roll, Θ_z	$\Delta B_x = -B_y \Theta_z$	$\Phi_b \Theta_z$	y_{co}
P	pitch, Θ_x	$\Delta B_z = B_y \Theta_x$		x-y coupling
Q	displacement, Δx	$\Delta B_y = B' \Delta x$	$K^2 L \Delta x$	x_{co}
U	displacement, Δy	$\Delta B_x = B' \Delta y$	$K^2 L \Delta y$	y_{co}
A	roll, Θ_z	$\Delta B_y = -2B' y \Theta_z$		x-y coupling
D		$\Delta B_x = 2B' y \Theta_z$		x-y coupling
S	displacement, Δy	$\Delta B_y = -2B'' y \Delta y$		x-y coupling
X		$\Delta B_x = 2B'' x \Delta y$		x-y coupling

Φ_b = bend angle of DIP, ρ = bend radius of DIP
L = lengths of Quad, $K^2 = B' / B \rho$

Table-2 shows the magnitude of the x_{co}^{max} , y_{co}^{max} closed orbit due to a 1 mrad point kick in the quadrupole or dipole using the design value of the lattice parameters. (see also Figs.1). Due to the fact that the integer part of ν_y is zero, the vertical orbit does not change sign thus the peak-to-peak orbit is $y_{co}^{p-t-p} \leq y_{co}^{max}$.

Table-2
Effects of point kicks in the XLS quadrupole and dipole

	Ψ mrad	x_{co}^{max} mm	where	x_{p-t-p} mm	y_{co}^{max} mm	where
Q	1	-1.17 +0.60	opposite Q closer ends of D's	1.77	1.52	middle of Dipoles
mid D	1	+0.27 -0.17	Quadrupoles opposite D	0.45	3.55	middle of opposite D
end of D	1	± 0.68	Quadrupoles	1.36	2.86	middle of opposite D

3. Closed orbit errors due to the main magnets.

3.1. Quadrupoles

The same quadrupoles are used in the Phase-1 and 2 machines. They will be aligned to $\Delta x, \Delta y \approx \pm 1mm$ accuracy. The effect of these misalignments on the closed

orbit is negligible as can be seen from the following considerations.

Fig. 1

Closed orbits due to $\Psi = 0.05$ mrad kicks at the middle of the straight section where the Q's and Sx's are located. The elements are also shown: $\square$ Dip's, $\triangle$ Q's, ∇ Sx's, $|$ PUE's.

There are four identical quadrupoles in the ring with $K^2 = 3.22 \text{ m}^{-2}$ and $L = 155 \text{ m}$. They are located at maximum β_x (2.2 m) and minimum β_y (1.6 m). The effect of a Δx or $\Delta y = .1 \text{ mm}$ misalignment is a kick of $\Psi_{x,y} = .05 \text{ mrad}$. This results (see Table-2) in a maximum horizontal closed orbit error of $x_{co} \approx -.06 \text{ mm}$ at the opposite Q, where β_x is maximum, and of $x_{co} \approx .03 \text{ mm}$ at the dipoles. The peak-to-peak value is therefore $\approx .09 \text{ mm}$. The maximum vertical closed orbit error is $y_{co} \approx .08 \text{ mm}$ at the middle of the opposite dipole, where β_y is maximum (this is also the peak-to-peak value since $\text{Int}(v_y) = 0$ and y_{co} does not change sign).

As seen from Table-1, a roll (rotation around the z-axis) can have an effect on x_{co} and y_{co} since it couples the x-y motion.

A random distribution of the misalignments of the quadrupoles (see [2]), yield a $\langle x_{co}^2 \rangle^{1/2} \approx .12 \text{ mm}$ and a $\langle y_{co}^2 \rangle^{1/2} \approx .18 \text{ mm}$ for the RMS of the maximum orbit displacements.

3.2. Sextupoles

The same type of sextupoles are used in the Phase-1 and 2 machines. They will be aligned to $\Delta x, \Delta y \approx \pm 1 \text{ mm}$ accuracy.

There are 2 identical Sx's in the ring, one between each Q-doublet, at the middle of the straight sections, where β_x is maximum (2.2 m) and β_y is minimum (1.6 m). A Δy misalignment of the sextupole can couple the x-y motion and thus can have an effect on x_{co} and y_{co} .

2. E.Close, M.Cornaccia, A.S.King, M.J.Lee: A proposed orbit and vertical dispersion correction system for PEP, PEP Note-271, 1978.

3.3. Dipoles

There are two 180° combined function (B' , B'' , $B''' \neq 0$) magnets in the ring. β_x have a minimum (.38 m) and β_y have a maximum (6.85 m) at the middle of the dipoles. Any misalignment of the dipole or of the superconducting coils (Phase-2) can lead to ΔB_x and ΔB_y field errors.

Both, the Phase-1 (warm) and Phase-2 (superconducting) dipoles will be aligned to Δx , $\Delta y \approx \pm 1 \text{ mm}$ and $\Theta \approx \pm 25 \text{ mrad}$ accuracy. In addition, in the Phase-2 dipoles the positioning error of the coils may be as large as Δx , $\Delta y \approx \pm 25 \text{ mm}$, which can also lead to a breaking of midplane symmetry (introducing ΔB_x field error).

3.3.1. ΔB_x , ΔB_y field errors

If there is a **uniform** dipole field error of $\Delta B_y/B_y$ over the lengths of the magnet, and it is identical in both magnets the horizontal closed orbit will simply be displaced by

$$x_{co}(s) = \frac{\Delta B_y}{B_y} \eta(s) = \frac{\Delta E}{E} \eta(s).$$

That is the particle just appears to be off energy and moves on the off energy closed orbit given by the dispersion function. The maximum value of the dispersion is $\eta_{\max} = 1.29 \text{ m}$ and it occurs in the focusing quadrupoles. A field error of $\Delta B_y/B_y = 10^{-3}$ gives rise to a $x_{\max} = 1.29 \text{ mm}$ horizontal orbit displacement.

The extended kick from the same uniform dipole field error in one dipole, or the point kick from a **localized** ΔB_y field error do to local coil position errors in the Phase-2 superconducting dipole, lead to relatively small x_{co} errors since $\beta_x = .36 \text{ m}$ in the dipoles.

If the coil position errors lead to a **break of the midplane symmetry**, then $\Delta B_x \neq 0$. A $\Delta B_x/B_y \approx 10^{-4}$ field error results in a kick of $\Psi_y \approx .3 \text{ mrad}$ and in a maximum $y_{co} \approx 1.1 \text{ mm}$ at the middle of the opposite dipole. The effect of the same magnitude of ΔB field error on the closed orbit is $\beta_y/\beta_x \approx 4$ times larger vertically than horizontally.

3.3.2. Fringe field errors

A deviation of the actual fringe field from the design fringe field can be treated as a point kick at the end of the dipole. The x_{co} closed orbit around the ring due to a $\Psi_x = \pm 1 \text{ mrad}$ kicks at the end of the dipoles are shown on Fig.2

3.3.3. Misalignments

Because of the 180° bend, the different kinds of misalignments, Δx , Δy , Δs , $\Delta \Theta_y$ (yaw), $\Delta \Theta_z$ (roll), and $\Delta \Theta_x$ (pitch) are mixed together. Furthermore, as pointed out before, the dipole has considerable quadrupole and higher harmonic fields. There—

Fig.2

$\Psi_x = \pm 1$ mrad kicks at the end (exit) of the dipole(s). (a) +1 mrad after one dipole only
(b) $\Psi_x = +1$, +1 mrad after the two dipoles, (c) $\Psi_x = +1$, -1 mrad after the two dipoles.

fore, misalignments which normally would not have effect on the closed orbit, might effect it in our case.

The effects of the different misalignments of the dipole was modelled using MAD [3]. In order to calculate the orbit inside the magnet, it was considered as consisting of 6 identical segments of $\alpha = \Phi_b/6$ bending angle each.

Let $\Delta X, \Delta Y, \Delta Z, \Theta_x, \Theta_y, \Theta_z$ refer to the misalignments of the whole magnet in its local coordinate system, while $\Delta x_i, \Delta y_i, \Delta z_i, \theta_{x,i}, \theta_{y,i}, \theta_{z,i}$ refer to the misalignments of the i-th segment in their local coordinate systems. With these notations the mixing of the misalignments were calculated in [4] as follows.

A ΔX misplacement of the (rigid) magnet results a combination of Δx_i and Δz_i misplacements of the i-th segment:

$$\Delta x_i = \Delta X \cos[(i-1)\alpha],$$

$$\Delta z_i = -\Delta X \sin[(i-1)\alpha]$$

A Θ_y yaw in the (rigid) magnet results in the i-th segment a combination of:

$$\Delta x_i = -\rho \Theta_y \sin[(i-1)\alpha]$$

$$\Delta z_i = -\rho \Theta_y [1 - \cos[(i-1)\alpha]]$$

A Θ_z roll of the (rigid) magnet is equivalent with a combination of roll, pitch and Δy

3. F.C.Iselin, J.Niederer: MAD user's reference manual, CERN/LEP-TH/87-33, 1987.

4. Eva S. Bozoki: Calculation of closed orbit errors due to misalignment of combined function magnets with large bend angle, Presented on the EPAC Conference, Nice, 1990.

misalignment of the i-th segment:

$$\begin{aligned}\Delta x_i &\approx 0, \\ \Delta z_i &\approx 0, \\ \Delta y_i &\approx \Theta_z \rho [1 - \cos(i-1)\alpha], \\ \theta_{x,i} &\approx \Theta_z \sin(i-1)\alpha, \\ \theta_{z,i} &\approx \Theta_z \cos(i-1)\alpha.\end{aligned}$$

A Θ_x pitch of the (rigid) magnet is equivalent with a combination of roll, pitch and Δy misalignment of the i-th segment:

$$\begin{aligned}\Delta x_i &\approx 0, \\ \Delta y_i &\approx \Theta_x \rho \sin(i-1)\alpha, \\ \theta_{x,i} &\approx \Theta_x \cos(i-1)\alpha, \\ \theta_{z,i} &\approx \Theta_x \sin(i-1)\alpha.\end{aligned}$$

Figs. 3a and b show the distorted horizontal closed orbit, x_{co} as a result of a $\Delta X = .25$ mm misplacement and $\Theta_y = .25$ mrad yaw of one of the bending magnet. It is interesting to note, that the ΔX and Θ_y misalignments of the magnet yield distorted closed orbit of very similar shape but strongly different magnitude. The same shape of orbit results from a point kick at the exit end of the magnet (but not at the middle of the magnet since the kick approximation of equ.(1) is not valid) as shown on Fig. 3c.

Figs. 4a, b and c show the distorted vertical closed orbit, y_{co} as a result of a $\Delta Y = -.25$ mm displacement, $\Theta_z = .25$ mrad roll and $\Theta_x = .25$ mrad pitch, respectively. The ΔY , Θ_x and Θ_z misalignments (especially the former two), yield closed orbits of a similar shape and different magnitude. This is due to the fact, that because of the small vertical phase advance across the magnet, the point kick approximation of equ.(1) is valid. This point is further illustrated by comparing the 4a-c orbits with the closed orbit resulting from a $\Psi_y = 1$ mrad kick at the middle of the magnet as shown on Fig. 4d.

Due to nonzero **sextupole** content, the effect of a Δy misalignment of the coils or of the dipole couples the x-y motion and thus can have an effect on x_{co} and y_{co} .

3.3.4. Summary of the effect of the dipole misalignments

Unlike in large rings with many magnets, where their misalignment is random, the two 180° magnet can be misaligned either in the same or in the opposite sense.

Fig. 3

Horizontal and vertical
closed orbit errors due to kick(s) and misalignments of one dipole.

Fig. 4

Table-3 summarizes the effect of the different types of misalignments in the dipole. The maximum (and the peak-to-peak) x_{co} , y_{co} as well as the max x'_{co} , y'_{co} are given for (i) misalignment in one dipole only, (ii) the two dipoles are misaligned in the same sense and (iii) the two dipoles are misaligned in the opposite sense.

Table-3
Effects of dipole misalignments
 x_{co}^{max} (x_{co}^{p-i-p}), y_{co}^{max} (y_{co}^{p-i-p}), x'_{co} and y'_{co} are given

	x	y	x'	y'	x	y	x'	y'	x	y	x'	y'
	mm				mm				mm			
	mrad				mrad				mrad			
	1 dipole only				2 dipoles, same				2 dipoles, opposite			
$\Delta x = .25\text{mm}$	.07(.13)	-	.4	-	.05(.13)	-	.3	-	.13(.26)	-	.5	-
$\Delta y = .25\text{mm}$	-	0.7(.4)	-	.3	-	0.9(.4)	-	.3	-	.4(.8)	-	.3
$\Theta_x = .25\text{mrad}$	-	0.4(.4)	-	.2	-	0.6(.3)	-	.2	-	.4(.7)	-	.2
$\Theta_y = .25\text{mrad}$	.4(.7)	-	.4	-	.3(.6)	-	.2	-	.7(1.3)	-	.8	-
$\Theta_x = .25\text{mrad}$	-	1.4 (.1)	-	.6	-	1.9 (.8)	-	.6	-	1.2(.2)	-	.6
1 mrad fringe field error	.7(1.4)	-	.9	-	.6(.9)	-	.9	-	1.3(2.7)	-	1.2	-

Fig. 5

The effect of (a) $\Delta y = \pm .25$ mm displacement of ϕ_x and ϕ_y betatron phase advance both dipoles and (b) $+.25$ and $-.25$ mm of the two dipoles respectively.

Fig. 6

4. Orbit monitors

There will be 4 PUE's, one at each end of the dipoles. In vertical betatron phase they are about evenly distributed ($\Delta\phi \approx 30$ and 45°) as can be seen from Fig. 6. Horizontally due to the 180° phase advance over the dipole, an additional monitor is

needed and will be available at the middle of both, the Phase-1 and 2 dipoles.

5. Orbit correctors

The constraint that the exit slits impose on the photon beamlines, requires that the source point, that is the closed orbit is controlled to better than $x_{co} \leq \pm 3$ mm, $y_{co} \leq \pm 2$ mm and $y'_{co} \leq \pm 1$ mrad. The actual closed orbit errors as calculated before, are smaller (horizontally) or about the same (vertically). However, in the following a monitor-corrector system is presented which allow the orbit to be controlled to much better accuracy.

5.1. Movable Q-Sx-Q assembly

This freedom will be used to adjust the straight sections to the measured magnetic midplane and effective magnetic lengths of the dipoles. The max movement of the assembly is $\Delta x, \Delta y = \pm 1$ mm (except in Phase-2, $\Delta x = 10$ mm).

5.2. Movable Q's

In addition to moving the Q-Sx-Q assembly, each Q can be moved by $\Delta x, \Delta y = \pm 3$ mm, which provides a maximum of ± 1.5 mrad kick. The four quadrupoles can be used as two correctors only since the quad doublets are very close to each other ($\phi_x \approx 10^\circ$ and $\phi_y \approx 14^\circ$, see Fig. 6). Either one quadrupole from each doublet can be used as corrector, or the two members of each doublet have to be moved jointly to provide a kick at the middle of the doublet.

Horizontally, even though the quads are at β_{max} , the kicks are effective only at the closer ends of the dipoles and at the opposite quadrupole (see Fig. 1a) and can not correct x_{co} in the dipoles very well. They work well correcting orbits like the ones on Figs. 2a and c, which show similar characteristics to the orbit due to a kick in the quadrupoles, but they can not correct orbits like the one on Fig. 2b. This will be illustrated later in sections 5.1 and 5.2.

Vertically their effect is limited by the fact that they are at β_y^{min} locations. They are most effective at the dipoles (see Fig. 1b). In certain cases, as will be illustrated in section 5.3, they can effectively correct y_{co} . However, they can not correct an orbit where y_{co} has different sign in the two dipoles (as shown on Fig. 5b) because a kick in the quadrupole produces y_{co} in the same direction in the two dipoles. This will be illustrated in section 5.5.

The movement of the Q's will be remote, computer controlled with an accuracy of ≈ 0.01 mm.

5.3. H/V corrector dipoles over the PUE's

Placing correctors over the PUE's is justified by their more even (then that of the quadrupoles) spacing in ϕ_x and ϕ_y . It will be shown in sections 5.1 and 5.2, that they provide better control of the orbit and with smaller kicks than correctors at the location of the quadrupoles.

5.4. H/V trim in the Dipoles

Having a horizontal corrector at the middle of the dipoles is desirable for two reasons. It is a high β_x location and it provides $\phi_x \approx 90^\circ$ spacing between the 6 horizontal correctors (4 at the PUE's and 2 at the middle of the dipoles).

Even though the phase advance is only $\approx 20^\circ$ across the dipole, the presence of vertical correctors in the dipole is important since β_y is maximum in the dipole and since errors in the dipole are the main sources of the closed orbit errors. They will be implemented in the Phase-2 dipoles.

6. Some typical closed orbit before/after correction

It was already pointed out, that the main source of closed orbit errors both horizontally and vertically are dipole misalignments. Furthermore, one can see from Figs. 3 and 4, that (i) yaw, Δx and "fringe field error" (kicks at the end of the dipoles) and (ii) pitch, roll, Δy and kick in the dipoles, produces the same types of closed orbit, respectively. Only the magnitude of the closed orbit is different for different types of misalignments in the two groups. In addition, since there are only two dipoles in the ring, their effect is either in the same or in the opposite direction. Therefore it is justified to examine only the following few types of closed orbits:

(H1), generated by an $\Psi_{x1} = 1$ mrad kick at the end of dipole-1

(H2), generated by an $\Psi_{x1} = \Psi_{x2} = 1$ mrad kick at the end of dipole-1 and 2.

(V1), generated by an $\Theta_{x1} = \Theta_{x2} = .25$ mrad pitch in dipole-1 and 2.

(V2), generated by an $-\Theta_{x1} = \Theta_{x2} .25$ mrad pitch in dipole-1 and 2.

For the orbit correction the ORBCOR [5] program was used with the MICADO [6]. algorithm. This chooses the correctors which has the most significant effect in minimizing the residual orbit. To force the use of certain correctors, the unwanted ones were disabled.

In this section the solid and dotted curves on the figures represent the before and after correction orbits, respectively. Small arrows are pointing to the location of the kicks. For each case, the total kick required for the correction ($\Sigma|\Theta_{kick}|$) and the maximum kick on one corrector (Θ_{kick}^{max}) as well as the before and after correction value of the RMS * and the peak-to-peak orbit is given.

6.1. Horizontal_1

The necessity of having a monitor in the dipole is illustrated on Figs. 7a,b. Even with only 4 correctors, both the peak-to-peak and the RMS orbits are better by a factor of ≈ 2.5 when monitors in the dipoles are used.

5. E.Bozoki: High level computer control of NSLS accelerator and storage rings, BNL-31351 NSLS Tech. Notes # 291, 296, 298 (1987), #305 (1988).

6. B.Autin, Y.Marti: Closed orbit corrections of A.G. Machines using a small number of magnets, CERN ISR-MA/73-17.

* In the horizontal cases RMS is always taken over the four PUE's and the middle of the two dipoles, while vertically only over the four PUE's.

The use of correctors at the middle of the dipoles (Fig. 7c) does not improve either the RMS nor the p-t-p orbit. Neither does it decrease θ_{kick}^{max} .

An improvement by a factor of ≈ 6 can be achieved in the RMS and the p-t-p orbits by using 6 monitors and 6 correctors (as indicated on Fig. 7b) with a maximum kick of ≈ 0.85 mrad on a PUE-corrector for the orbit discussed, that is to correct fringe field errors up to 0.5 mrad on one or up to 0.25 mrad on both dipoles, or yaw errors up to 0.25 mrad on both dipoles (see Table-3).

As a comparison Fig. 7d shows the case when Q4-Q1 and Q2-Q3 are used as two correctors. (The additional use of correctors in the dipole leads to a very similar result). The improvement in the RMS and p-t-p orbits are by a factor of ≈ 2.2 .

Fig. 7

6.2. Horizontal_2

The results of the correction of the H1 and H2 orbits are very similar as can be seen from Figs. 8. Here again, (i) the need of monitors at the middle of the dipoles and (ii) the insufficient nature of using the quadrupoles as orbit correctors are apparent.

A very good orbit correction can be achieved by using 6 monitors and 4 or 6 correctors (as indicated on Fig. 8b or 8c) with a maximum kick of ≈ 0.7 - 0.9 mrad on a PUE-corrector for the H2 orbit. Approximately half of that is sufficient to correct fringe field errors up to ± 0.5 mrad or yaw errors up to ± 0.25 mrad (see Table-3).

Fig.8

6.3. Vertical_1

This type of orbit can be easily corrected with 4 monitors (PUE's) and either by using the correctors (a) in the dipoles or (b) at the PUE's, or (c) by moving the quadrupoles. In all cases $\theta_{kick}^{max} \leq .4$ mrad (see Figs. 9).

6.4. Vertical_2

This type of orbit can be easily corrected with 4 monitors (PUE's) and either by using the correctors (a) in the dipoles or (b) at the PUE's. In both cases $|\Theta_{kick}^{max}| \leq .5$ mrad. This type of orbit however, can not be corrected (c) by using the quadrupoles as pointed out earlier in section 4.2 (see Figs. 10).

Figs. 9

Figs. 10

7. Conclusions

The main source of closed orbit distortions in the SXLS ring are the 180° combined function dipoles, and the largest closed orbit errors are caused by the Θ_y and Θ_x rotations of those magnets. Misalignments of ± 0.25 mm and ± 0.25 mrad (design tolerance limit on the placement of the magnet) and fringe field errors corresponding to ≤ 0.5 mrad kicks at the end of the dipole(s), result in closed orbit errors of $|x_{co}| \leq 0.7$ mm and $|y_{co}| \leq 1.9$ mm. These errors are less (horizontally) or equal (vertically) than allowed by the constraints on the photon beam-lines. However, an orbit monitor-corrector system was designed which allows the both orbits to be controlled to better than .2 mm accuracy.