CLOSED ORBIT CORRECTION OF HEFEI ADVANCED LIGHT SOURCE (HALS) STORAGE RING*

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Abstract

In order to meet the increasing requirements of synchrotron radiation users, a new plan of VUV and soft X-ray light source, named Hefei Advanced Light Source (HALS), is brought forward by National Synchrotron Radiation Laboratory (NSRL). This 1.5GeV storage ring with ultra low emittance 0.2nmrad consists of 18 combined FBA cells and the circumference is 388m. Strong enough quadrupoles and sextupoles must be needed for getting such low emittance lattice, which will lead beam close orbit distortions' (COD) sensitivity to the field and alignment errors in magnets. Estimation of the COD from various error sources is investigated. Using orbit response matrix and singular value decomposition method, the distribution of beam position monitors and the location of correctors are reported in the paper. Simulation proves that COD can be corrected down to 60 microns level. In the same time the corrector strengths are weaker enough in the correction scheme.

INTRODUCTION

Hefei Light Source (HLS) of National Synchrotron Radiation Laboratory is a dedicated second generation light source. In order to obtained synchrotron radiation with high brightness and better coherence in the VUV and soft X-ray range for users, A plane of building a new machine named HALS storage ring has been brought forward [1]. In the preliminary design, considering the required low emittance, the straight lines' number and length, A FBA lattice structure with 18 super-periods has been chosen for HALS. Figure 1 shows the β and dispersion functions of one cell, from which we can see there is no dispersion in straight sections. Main parameters about HALS storage ring can be founded in table1 [2].

In the design, strong quadrupoles and sextupoles have been used because of the low emittance lattice structure. The magnet alignment errors will lead to larger closed orbit distortion (COD), which can induce unwanted side effects. The non-linear effect can make the dynamic aperture and beam lifetime decreasing. Furthermore, it will change the synchrotron light's position at the beamline front ends, which can influence the brightness at experiment station. In order to correct the COD, Beam Position Monitors (BPMs) and correctors must be installed.

In the paper, COD is estimated considering alignment errors in magnets and girders. Magnets field errors are also included. Using SVD method, the closed orbit distortions are corrected. In the same time, corrector strengths and residual closed orbit distortions are obtained.

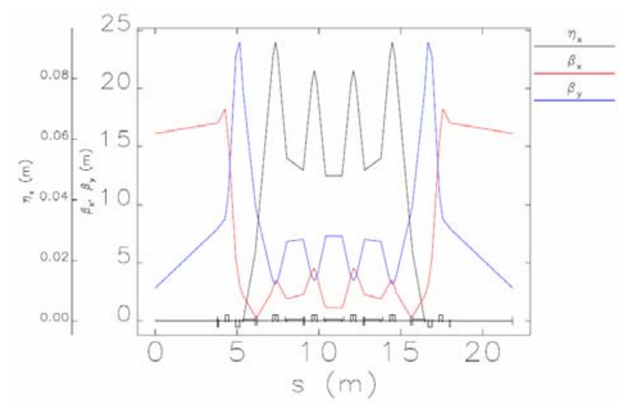

Figure 1: β and dispersion functions of one cell.

Table 1: Main Parameters of HALS Storage Ring

Parameters	Values
Circumference	388m
Energy	1.5GeV
Lattice structure	FBA
Super-period number	18
Straight section length	7.6m
Emittance of bare lattice	0.27 nm·rad
Emittance with damping Wigglers	<0.20 nm·rad
Transverse tunes	29.32/10.28
Natural chromaticities	-55/-51
Momentum compaction factor	0.00047
Energy spread	0.00022
Harmonic number	648

ERROR SOURCES CONSIDERATION

In lattice design, the closed orbit distortion induced by errors of magnetic field and misalignment of magnets is a critical factor. In a storage ring, for the distributed dipole field errors, the closed orbit can be expressed as:

$$y_{co}(s) = \frac{\sqrt{\beta(s)}}{2\sin(\pi\upsilon)} \sum_{i=1}^{N} \sqrt{\beta_i}\,\theta_i \cos\left(\pi\upsilon - \left|\phi(s) - \phi_i\right|\right)$$

where β_i, θ_i and ϕ_i are values at the kicker location.

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$\theta_i = (\Delta B_i \cdot l_i)/B\rho$ is kick angle from dipole field errors. The dipole field errors mainly include quadrupole misalignments in horizontal and vertical planes, dipole fields errors in in horizontal plane, dipole rotation errors in vertical plane [3,4].

As with most synchrotrons, closed-orbit amplification factors(COAFs) contribute the most significant tolerance to be handled. COAFs give the rms closed-orbit distortion around the ring per unit of rns alignment error for all the quadrupoles in the ring, where the error assuming to be a random normal distribution. The COAF is shown in Figure 2 for one cell. One can see, like other advanced synchrotron light sources, average value of COAF in each plane is a little greater than 50. This means if the rms alignment error in the quadrupoles is 0.1mm, an average closed-orbit distortion can reach 5mm. This closed orbit error in the sextupoles contributes to a nonlinear focusing error in the lattice, which will make the dynamic aperture decreasing.

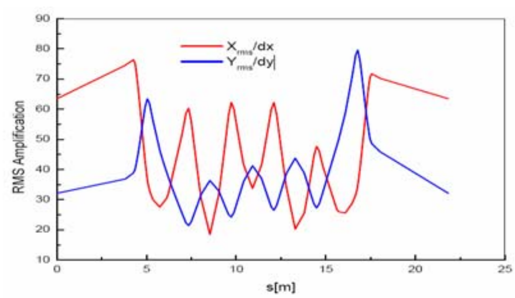

Figure 2: The COFA of quadrupoles.

In order to reduce the alignment errors of the magnets, the clusters of quadrupoles and sextupoles will be positioned on accurately machined individual girders[4,5]. In the preliminary design, there are five girders in one cell with symmetrical layout. Three quadrupoles，one sextupole and one dipole are on the 1# and 5# girders respectively. One quadrupole, two sextupoles and one dipole are on the 2# and 4# girders individually. Two quadrupoles, two sextupoles and one dipole are on the 3# girder. Their magnetic centers can be aligned precisely with respect to the girder fiducials. Consulting typical high performance synchrotron light sources [5,6,7], basic tolerances for the alignment and field error of HALS are chosen as follows.

（1） Girder transverse displacement rms error is 0.1 mm and rotation rms error is 0.1mrad.

（2） Dipole transverse displacement rms error is 0.1 mm and rotation rms error is 0.1mrad respect to girder. Dipole field rms error is 0.02%.

（3） Quadrupole and sextupole transverse displacement rms error with respect to girder: 0.03 mm.

CLOSED ORBIT CORRECTION

Considering a set of small dipole perturbation given by θ_j , j=1,…,N_b, where N_b is the number of dipole kicks. The response matrix **R** can be defined as $y_i = R_{ij}\,\theta_j, j = 1,\ldots,N_b \; i = 1,\ldots,N_m$, where y_i is the measured closed orbit from dipole perturbation standing for either horizontal or vertical direction. N_m is the BPMs number. **R** is equal to the actual machine's Green's function $R_{ij} = G_y(s_i, s_j)$, where

$$G(s_i, s_j) = \frac{\sqrt{\beta(s_i)\beta(s_j)}}{2\sin\pi\upsilon}\cos\left(\pi\upsilon - \left|\phi(s_i) - \phi(s_j)\right|\right)$$

The outcome of response matrix modelling depends on the BPM resolution, dipole kickers and BPMs' number, etc. Let $y_{i,co}$ and Δ_i be the closed orbit deviation and BPM resolution of the ith BPM. By varying the correctors strength θ_j, one can minimize the value $\sum_{i=1}^{N_m} \frac{|y_{i,co}|^2}{\Delta_i^2}$ to correct the closed orbit distortion [3].

As a rough guideline, the BPMs should be spaced by about 90º in phase advance. They also should be placed close to the quadrupoles to reduce the COD or close to the sextupoles to reduce the feed-down effects including COD, coupling and tune shifts. As Figure 3 shown, horizontal tune in one cell is 1.63 and vertical tune is 0.58. From the horizontal phase advance, it is clear that at least one BPM is required in each straight section to have better control of the stable light sources from insertion devices. In the preliminary design, about eleven BPMs per cell should provide good coverage. Distribution of BPMs in one cell is shown in Figure 4.

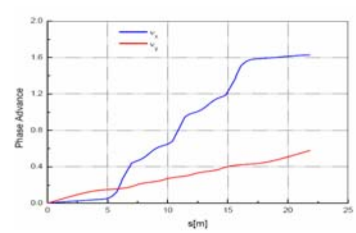

Figure 3: Normalized phase advance for one period.

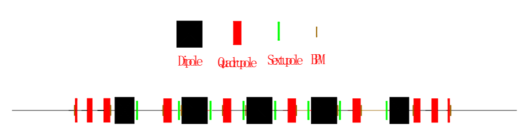

Figure 4 : The position of BPMs in one cell.

In order to center the orbit in all the BPMs, one corrector for each BPM is needed. The number of correctors can be reduced in the vertical plane, since the cell tune is about 0.6. Using SVD method, eleven correctors are chosen in one cell. Nine of these correctors work in horizontal plane and five in vertical plane. There are no individual correctors in HALS storage ring because of space limitation. Some are located within quadrupoles with additional coils and others within sextupoles.

Figure 5 shows the COD in horizontal and vertical plane after correction in HALS storage ring for 200 different schemes of errors. During the simulation [8], BPM transverse displacement error is 0.03mm respect to the girder. After statistical analysis, conclusions can be gotten that the corrected horizontal rms COD is below 0.040 mm and the vertical rms COD is below 0.062mm.

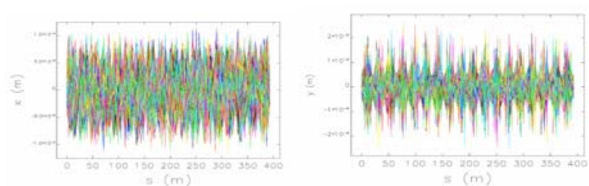

Figure 5: Corrected horizontal and vertical COD in HALS storage ring.

Horizontal and vertical dispersions after correction are shown in Figure 6 for 200 different schemes of errors. One can see that the horizontal dispersion can be corrected well and the rms vertical dispersion is below 5mm.

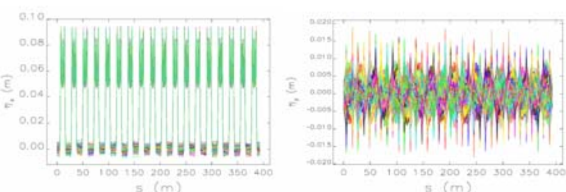

Figure 6: Dispersion after correction in HALS storage ring for 200 different scheme of errors.

To avoid breaking the symmetry of the linear optics, it is the main objective for the global orbit correction system to establish and maintain the orbit at the magnetic centers of the sextupoles. Figure 7 shows the histogram of beam position relative to sextupole centers[8]. Conclusion can be gotten that Xoffset rms value relative to sextupole centers is 0.024mm and Yoffset rms value is 0.038mm. Considering the transverse displacement of sextupoles, Courant–Snyder parameters will be disturbed. After correction, maximum, minimum and mean values about β and dispersion functions are shown in Figure 8. It is clearly that all of them can be corrected well.

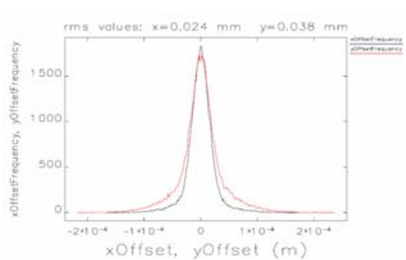

Figure 7: Histogram of beam position relative to sextupole centers.

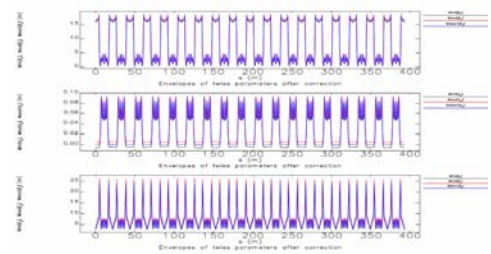

Figure 8: Maximum, minimum and mean value of beta and dispersion function after correction.

Figure 9 shows the histograms of corrector kicks strength in horizontal and vertical direction, from which, one can see the rms corrector strengths are smaller than 0.25mrad in both transverse directions.

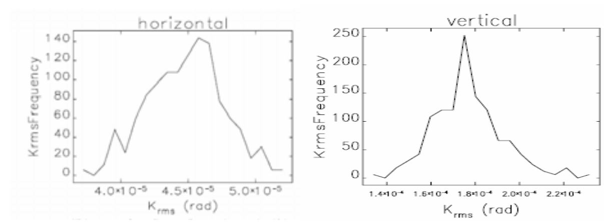

Figure 9: Distribution of rms corrector strengths.

CONCLUSION

COD based on typical displacement and field errors of magnets are estimated in the HALS storage ring considering the effects about displacement errors of girders and BPMs. Number and position of BPMs and correctors are optimized using response matrix and SVD method. After correction, rms COD can be restricted under about 0.06mm level. Beta and dispersion functions can also be corrected well. Simulation also proves that correctors can work with weaker strength.

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