EFFECTS ESTIMATION OF SUPERCONDUCTING WIGGLER IN SSRF

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Abstract

Superconducting wiggler (SW) may greatly impact on the beam dynamics in a storage ring. The effects of a 4.5T SW has been studied in SSRF including impaction on the emittance and the energy spread. To keep an undegraded storage ring performance, a local achromatic lattice is considered. The combat between the damping effect of the SW and emittance growth of local achromatic lattice is the main concern of this paper. Other effects (tune shift, beta beating, dynamic aperture, etc.) with the SW are also simulated and optimized in this paper.

INTRODUCTION

Shanghai Synchrotron Radiation Facility (SSRF) is a third generation light source at an intermediate energy 3.5GeV [1]. Five beam lines with insertion device (ID) have been constructed opened to users. In the coming program of phase II, one SW is going to be set in. With the peak magnetic field of 4.5T, the SW will greatly impact the beam dynamics of the storage ring, while the existing five IDs only have slight effects to SSRF. Main parameters of the existing five IDs and the coming SW are listed in table 1.

Table 1: Main Parameters of IDs in SSRF

ID	λ_{ID}	L_{ID}	$B_{y,max}$
EPU	10cm	4.2m	0.6T
Wiggler	8cm	1.6m	1.2T
Wiggler	14cm	1.4m	1.9T
IVU	2.5cm	2m	0.94T
IVU	2.5cm	2m	0.94T
SW	4.8cm	1.08m	4.5T

Simulation result of Accelerator Toolbox (AT) [2] shows that, due to introduction of the SW, emittance will increase 55%, while the energy spread almost keep constant, which were confirmed by formulae calculation. To keep good quality of beam, the optic was optimized. The beating of lattice function was depressed to a very small level, and the emittance increasing factor was corrected to 39% with the energy spread still remain nearly the same.

Since reducing the dispersion at the SW straight would help to reduce the SW exciting effect to the emittance, a local achromatic optics was considered. A solution was achieved with ten quadrupoles involved. The emittance increased 14% in the achromatic scheme, and the increasing factor was only 3% after SW in. Dynamic aperture degraded, but still enough for injection. Tune shift and beta beating were very small.

Another scheme was studied, in which the SW damping and exciting effect on emittance was almost balanced, so as to keep unchanged emittance after SW introduced.

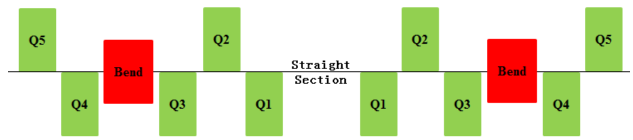

Figure 1: Layout of lattice between 2 arcs.

TOOLS FOR ESTIMATION

The emittance and energy spread can be written as [3]:

$$\varepsilon_x = \varepsilon_{x0}\left(\frac{1+\frac{2L_{ID}\rho_0^2}{3\pi^2 f_h \rho_{ID}^3}}{1+\frac{L_{ID}\rho_0}{4\pi\rho_{ID}^2}}\right), f_h = \frac{<H>}{\bar{H}} \quad (1)$$

$$\sigma_E = \sigma_{E0}\sqrt{\frac{1+\frac{2L_{ID}\rho_0^2}{3\pi^2 \rho_{ID}^3}}{1+\frac{L_{ID}\rho_0}{4\pi\rho_{ID}^2}}}, f_h = \frac{<H>}{\bar{H}} \quad (2)$$

$< H >$ represents the average of H-function in the dipole of the whole ring, and $\bar{H}$ as in the insertion device. The emittance and energy spread is only affected by the length and field strength of the insertion device.

Simulation was carried out with AT. The insertion device was considered to be hard-edged and as a series of slices of dipoles. The magnetic field was assumed to be sinusoidal.

Table 2: Simulation & Calculation Comparison

	Emittanc (nm.rad)		
	No ID	**5ID**	**5ID+SW**
Simulation	3.91	3.99	6.18
Calculation	-	4.00	5.98
	Energy spread (1e-4)		
	No ID	**5ID**	**5ID+SW**
Simulation	9.83	9.79	10.75
Calculation	-	9.76	11.72

Emittance and energy spread simulated by AT and calculated by formulae are shown in table 2. There is only a small deviation between the two methods, i.e. the simulation method was believable.

CORRECTION SCHEME

Quadrupoles adjacent to SW (Q1 Q2 Q3 in figure 1) were chosen to correct the optics. As shown in figure 2, the optics was well restored, and the emittance increasing factor has reduced to 39% from the uncorrected 55%. Main parameters of the machine are shown in table 3.

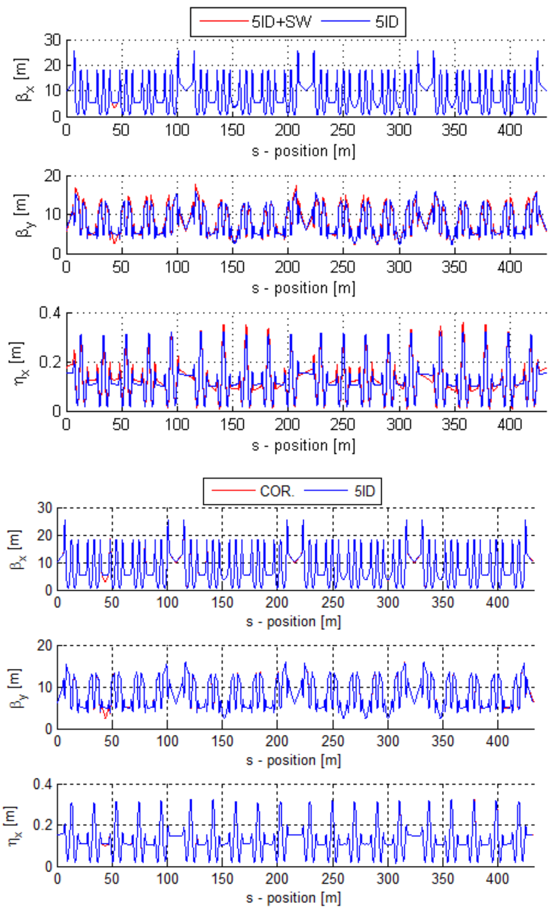

Figure 2: The uncorrected optics (upper fig) and the corrected optics (under fig) comparing with the normal.

Table 3: Machine Parameters of Different Lattice

	5ID	5ID+SW	COR.
Emittance (nm)	3.99	6.18	5.53
Energy spread	9.8e-4	10.7e-4	10.7e-4
Radiation loss (MeV)	1.521	1.689	1.689
Tune	22.22 11.30	22.22 11.31	22.25 11.32
Chromaticity	-7.34 0.90	-7.29 1.06	-7.39 0.95
Alpha	4.3e-4	4.3e-4	4.3e-4
Max beta (m)	25.4 15.9	25.4 17.6	25.5 15.9
Max eta (m)	0.321	0.358	0.321
Energy acceptance	3.75%	3.57%	3.58%
Bunch length (ps)	12.1	13.3	13.3
Beta beating	-	0.00% 6.54%	0.43% 0.66%
Eta_x beating	-	11.90%	0.12%

The on-momentum dynamic aperture almost keeps the same, which means the injection would not be affected. The tracking result of 1000 turns was shown in figure 3.

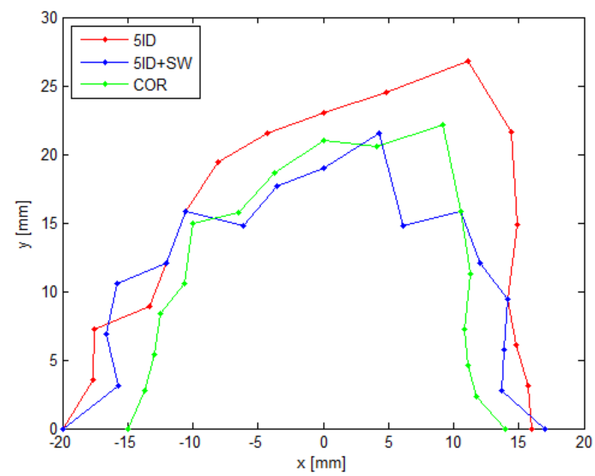

Figure 3: Dynamic aperture of: normal 5ID lattice (red), putting SW in normal lattice (blue), and then optics corrected (green), with 1000 turns tracking by AT.

ACHROMATIC SCHEME

The eta function from S0 to S1 could be calculated in matrix by [4]:

$$\begin{bmatrix}\eta\\ \eta'\\ 1\end{bmatrix}_1 = M_{3\times3}\begin{bmatrix}\eta\\ \eta'\\ 1\end{bmatrix}_0 = \begin{bmatrix} & N_{2\times3} & \\ 0 & 0 & 1\end{bmatrix}\begin{bmatrix}\eta\\ \eta'\\ 1\end{bmatrix}_0 \qquad (3)$$

$M_{3\times3}$ is the transfer matrix from S0 to S1.

There were two constraint equations, so two quadrupoles were needed to make achromatic optics at the exit of bending magnet. Meanwhile, another six quadrupoles were needed to match beta function, alpha function and tune. In a word, at least eight quadrupoles were needed for this scheme. Practically all the ten quadrupoles in the upstream and downstream cell were involved to achieve this scheme.

A solution is shown in figure 4. The opitcs could be greatly saved. In achromatic section, eta function was completely depressed to zero, and beta function at the SW straight kept unchanged. The emittance increased 14% in the achromatic scheme, but the increasing factor was only

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3% after SW in. Tune shift was 0.0001 and 0.0162, in horizontal and vertical plane respectively.

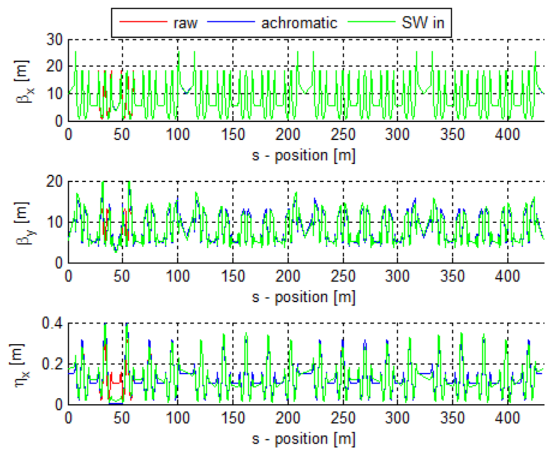

Figure 4: Optics of achromatic scheme comparing with the raw lattice.

In the achromatic scheme, the dynamic aperture reduced, but still enough for injection, and kept nearly the same after SW in. The tracking result of 1000 turns was shown in figure 5.

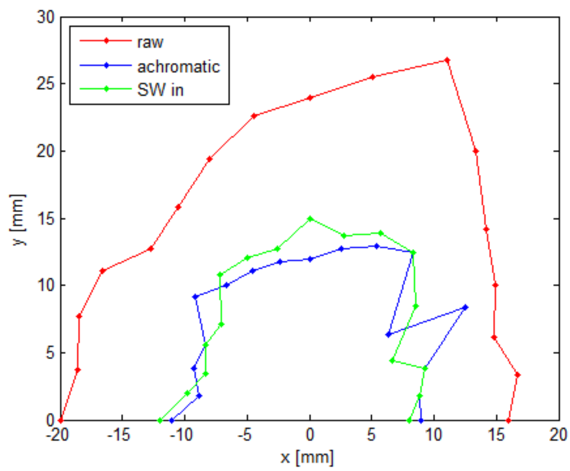

Figure 5: Dynamic aperture of: raw lattice (red), achromatic scheme (blue), and SW in the achromatic scheme (green), with 1000 turns tracking by AT.

COMPROMISED SCHEME

Another scheme to balance the damping and exciting of SW was also studied. The eta function was corrected to about 60mm from about 110mm in 5ID lattice, and the emittance got to 4.82nm from 3.99nm, i.e. increased 21%. With SW put in, the emittance was 4.80nm, almost unchanged by SW. The dynamic aperture almost restored, as shown in figure 6, but beta beating and tune shift still need to be optimized. Further optimization is on-going.

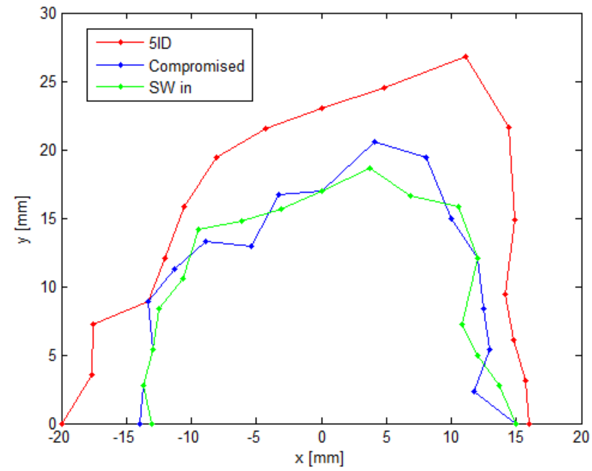

Figure 6: Dynamic aperture of: normal 5ID lattice (red), compromised scheme with eta function depressed (blue), and SW in the compromised scheme (green), with 1000 turns tracking by AT.

CONCLUSION

The effects of 4.5T SW on beam dynamics in SSRF had been calculated and simulated and great impact was found. The emittance would rise by 55%, which would greatly reduce the brightness of synchrotron radiation. To restore the performance of machine, correction for lattice function was implemented, and the emittance would rise by 39% then. For further optimization, local achromatic lattice was considered. The emittance increasing factor was 14% in achromatic scheme, and reduced to 3% after SW in. The dynamic aperture degraded, but still enough for injection. Another compromised scheme was studied, in which the damping and exciting effect of SW was balanced. The increasing factor of emittance was 21%, but beta beating and tune shift still need to be optimized.

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