LATTICE OPTIMIZATION FOR THE SSRF STORAGE RING

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Abstract

Shanghai Synchrotron Radiation Facility (SSRF) is a low emittance third-generation synchrotron radiation light source under design. According to the increasing demands in high brightness and high flux density hard x-rays applications and the continuing advances in mini-gap insertion devices and top-up injection, the lattice performance of SSRF storage ring has been re-optimized. The new lattice conducts an emittance of 3nm-rad at 3.5GeV, 432m in circumference, three types of straight section in length and enough adjusting flexibility of beta function and dispersion function at straight section. Tracking studies show that this lattice has large enough dynamic apertures and energy acceptance even with multipole field errors of magnets.

INTRODUCTION

Shanghai Synchrotron Radiation Facility (SSRF), as a future medium energy third-generation light source, aims at providing powerful X-rays to Chinese SR users in a variety of research fields, the R&D work was completed in 2001[1-3]. The lattice of SSRF storage ring has been evolved to a cost effective machine over the past five years [4, 5], and has already featured with the design goal and ideas at that period. However, the previous lattice design didn't pursue extreme low beam emittance.

In recent years, new accelerator technologies, such as super-conducting RF cavity system, top up injection and mini-gap undulator, are becoming matured and widely used especially in medium energy light sources, and make it possible for medium energy SR light source to provide high brightness and high flux X-rays [6, 7]. With the developing of life science especially bio-crystallography, demand of users for higher brilliance in the hard X-ray increased very quickly [6-8]. Thus, we have re-optimized the storage ring lattice performance to ensure that SSRF will be the first class light source in the world when it is constructed in the near future.

Although the previous lattice design has overcome the difficulties among limited circumference (396 m), higher beam energy (3.5GeV) and high flexibility (high horizontal and hybrid horizontal beta functions operation mode), completely realized the SSRF design goal at that time, that lattice has some disadvantages: (1) large emittance of 4.8~11.8nm.rad, (2) not optimizing for top-up injection, (3) horizontal beta functions either too large not ooptimizing for wiggler or too small not optimizing for installing mini-gap undulator. Thus, based on the basic lattice, we have therefore re-optimized the lattice performance for the SSRF storage ring. The main issues of optimization are (1) to further make ring emittance lower by incorporating focusing gradient in the bending magnet, (2) to use four long straight sections of 12m, which are especially necessary for installing all injection pulsed kick and septum magnets in one straight section to satisfy perfect top-up injection requirements, for an example, to decouple closed bump orbit with some nonlinear magnets such as sextupoles, and the ring circumference increased from 396 m to 432 m, (3) to choose the horizontal beta function in range from L/2 to L in the middle of straight section to meet beam size requirements for users, to choose the vertical beta function close to L/2 and as small as possible for the installation of mini-gap undulator..

NEW LATTICE

Linear Optics

The new version lattice of SSRF storage ring is a four-fold symmetry structure. Each super period includes five DBA cells, one 12.0m long straight section, two 7.0m medium straight sections and two 5.0m short straight sections. The main parameters of the storage ring are summarized in Table 1, and the electron beam size parameters at light source points are listed in table 2. Among the four long straight sections, one is used for installing three superconducting RF cavities, another is used for installing injection pulsed kick and septum magnets, the other two are kept for installing long insertion devices. And other sixteen straight sections can be used to install insertion devices (wiggler or undulator).

Table 1: Main Parameters of the SSRF Storage Ring

Version	New	Old
Energy (GeV)	3.5	3.5
Circumference (m)	432	396
Harmonic Number	720	660
Nat. Emittance (nm·rad)	2.95	4.8~11.8
Multi-Bunch (mA) Single-Bunch (mA)	200~300 >5	200~300 >5
Straight Lengths (m)	4×12.0 8×7.0 8×5.0	10×7.24, 10×5.0
Betatron tunes, Q_x/Q_y	22.24/11.23	22.19/8.23
Momentum Compaction	5.2×10^{-4}	6.9×10^{-4}
RF Frequency (MHz)	499.654	499.654
RF Voltage (MV)	4	4
Energy loss/Turn (MeV)	1.256	1.256
Beam Lifetime (hrs)	>15	>20

Table 2: Beam size at source points (1% coupling)

Source Point	σx [um]	σx' [urad]	σy [um]	σy' [urad]
Short Straight Sections	147.8	31.4	7.7	3.8
Long Straight Sections	155.7	29.0	8.6	3.4
Super-long Straight Sections	228.0	17.2	12.1	2.4
Bending * (Near Short)	62.0	79.4	20.9	3.6
Bending * (Near Long)	60.3	81.3	22.7	2.8
Bending*(Near Super-long)	57.1	83.5	26.1	1.3

*source are extract at bending magnet at three degree from its upstream.

The performance of the storage ring lattice is determined by the choice of betatron tunes and beta functions in straight sections. One choice of the betatron tunes of the SSRF storage ring is Qx=22.24 and Qy=11.23. Here, the horizontal beta functions are chosen to be 10m, 3.5m and 3.0m, and vertical beta functions are of 5.0m, 2.5m and 2.0m, the horizontal dispersion functions are of 0.15m, 0.118m, 0.114m in the middle of long, medium and short straight sections, respectively. The resulting structure has a natural horizontal emittance ε_{x0}=2.95 nm·rad and the lattice functions are shown in figure1.

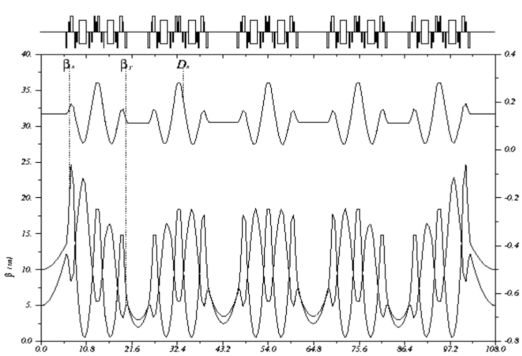

Figure 1: Lattice functions of a SSRF ring super-period.

Figure 2 shows the schematic layout of a half super-period of the SSRF storage ring. Each DBA cell contains 2 combined bending magnets, 10 quadrupoles, and 7 sextupoles. The bending angle of each bending magnet is 9 degree, and its magnetic field is 1.105T with focusing gradient of 2.333T/m, and its effective length is of 1.66 m. There are total 200 quadruple magnets in four kinds of length, 20cm, 30cm, 40cm and 60cm, and fifteen families. The quadrupoles are powered separately and the maximum operation gradient is 20T/m. Sextupoles are divided into two kinds of length, 20cm and 24cm, and in order to compensate the nonlinear disturbance on the storage ring due to various insertion devices, each sextupole is powered also separately with its maximum gradient of 450T/m. As there are 10 quadrupoles in each DBA cell, the SSRF storage ring magnet lattice has high flexibility. The betatron tunes and beta functions can be easily adjusted within a wide range depending on user requirements.

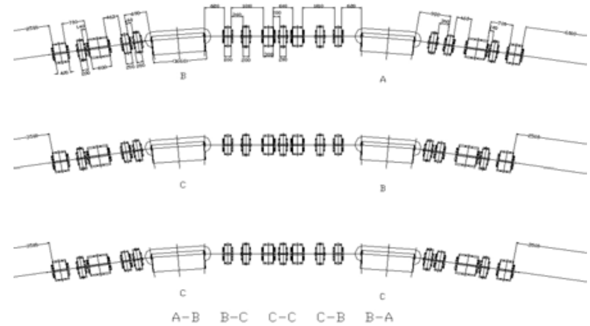

Figure 2: Layout of a half SSRF ring super-period.

Non-linear Optics

The inclusion of long straight sections: (1) changes the relative phase advance between sextupoles, (2) reduces the fold of symmetry from 10 to 4, and one can expect a reduction of the dynamic aperture. There are 7 sextupoles in each DBA cell. Two families of sextupoles (SF and SD) can be adjusted to correct the chromaticity in both planes. Unfortunately, the dynamic aperture of the SSRF storage ring lattice with the chromaticity-correction sextupoles only (SF and SD) is very small. To enlarge the dynamic aperture, six families of harmonic sextupoles (SLF, SLD, SMF, SMD, SSF, SSD) are introduced in the lattice. The OPA code [9] is used to optimize harmonic sextupole strengths to suppress the third order resonance coefficients, to reduce the tune variation of with amplitude, and then the dynamic aperture as well as the momentum acceptance of the storage ring is enlarged. The dynamic aperture can be determined by tracking individual particle around the storage ring. Usually, particles are considered to be stable if they track for 1000 turns or more. In our design, MAD [10, 11] has been used to determine the dynamic aperture.

After optimization, the horizontal on-momentum (dp/p=0.0) dynamic aperture in the middle of long straight section reaches 30mm and the momentum acceptance is larger than 3%. Figure 3 shows the dynamic aperture in the middle of long straight sections of the storage ring without magnetic imperfections, simulated by use of the MAD8.23DL code[10]. The horizontal and vertical chromaticities are corrected to plus one. The dependence of the betatron tunes upon momentum deviation is shown in figure 3. The horizontal tune change, up to momentum deviation of 3%, is less than 0.05, and the vertical one is less than 0.045.

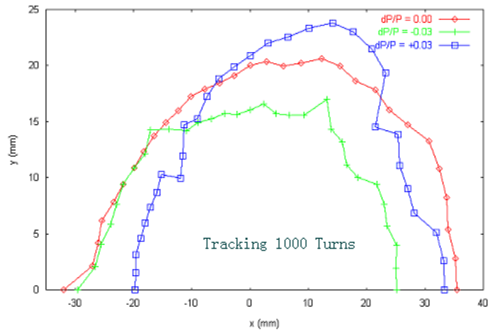

Figure 3: Dynamic aperture tracking in the middle of long straight section.

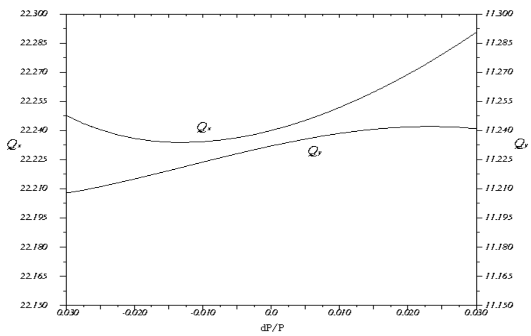

Figure 4: Momentum dependent tune shift.

The magnetic imperfections disturb the motion of electrons in the storage ring, resulting in reduction of dynamic aperture. The reduction of dynamic aperture of the SSRF storage ring, caused by magnet field errors, has been investigated by tracking. The random main field errors, and random and systematic multipole errors are included. In addition, feed-down multipole fields due to a large trajectory in the dipoles are also included. The rms main field errors of quadrupoles and sextupoles due to differences in magnetic core length are assumed to be 5×10^{-4} and 1×10^{-3}, respectively. The multipole errors for dipoles, quadrupoles and sextupoles used in the study are defined in terms of ratio of the multipole field ΔB_n (normal or skew) to main magnet field B at a radius R_{ref}, where n=1,2,…, is the multipole order starting with dipole.

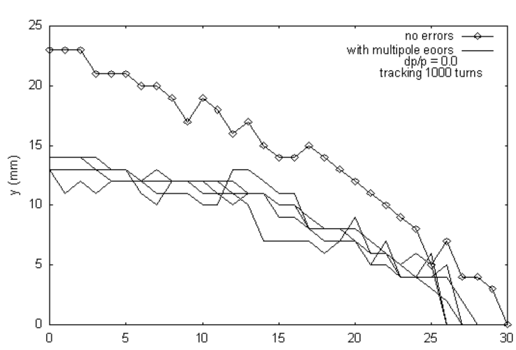

Figure 5: Dynamic aperture with magnet errors.

The normal systematic and random rms values $\Delta B_n/B_N$ used in the simulations, which are taken from SPEAR3 magnets [13].

Figure 5 shows on-momentum (dp/p=0) dynamic apertures in the middle of long straight section with magnet multipole field errors tracking by using RACETRACK[12]. From this figure, it can be seen that the dynamic aperture (with errors) of the SSRF storage ring is larger than 20mm, which is large enough to meet the requirements for efficient injection and long beam lifetime.

CONCLUSIONS

The performance of SSRF storage ring can be improved by adopting bending magnet with focusing gradient in its lattice. The top-up injection is also feasible by using long straight section of 12m. The optimized lattice therefore has small emittance about 3 nm.rad and enough flexibilities, the beta function and dispersion function in the middle of straight section can be changed within wide range depending on user needs. Tracking studies show that this lattice has large enough dynamic apertures and energy acceptance to meet the beam injection and beam lifetime requirements even with multipole field errors of magnets.

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