# Lattice Design for SSRF Storage Ring*

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**Abstract** Shanghai Synchrotron Radiation Facility (SSRF) is a low emittance third-generation synchrotron radiation light source under construction.The lattice performance of SSRF storage ring has been optimized. The lattice conducts an emittance of 3.9nm·rad at 3.5GeV, 432m in circumference, two types of straight sections 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.

**Key words** SSRF, emittance, top-up injection, lattice, dynamic aperture

## 1 Introduction

Shanghai Synchrotron Radiation Facility (SSRF), as a 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]. The lattice of the storage ring has been evolved to a cost effective machine over the past five years[2, 3].

In recent years, super-conducting RF cavity system, top up injection and mini-gap undulator, are becoming matured, and make it possible for medium energy SR light source to provide high brightness and high flux X-rays[4—6]. With the developing of bio-crystallography, users for higher brilliance in the hard X ray increase very quickly[5]. Although the old lattice design[3] has over-come the difficulties among limited circu-mference (396m), 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 5.8—11.8nm·rad, (2) not optimize the lattice for top-up injection, (3) horizontal beta functions are either too large or too small, not suitable for installing wiggler and mini-gap undulator simultaneously.

Thus, based on the basic lattice, we have re-optimized the lattice performance. The main issues of optimisation are (1) to further make the emittance lower by using distributed dispersion at straight sections, (2) to use four long straight sections of 12m, which are especially necessary for perfect top-up injection requirements, such as, to decouple closed bump orbit with sextupoles, and the ring circumference increased from 396m to 432m, (3) to choose the horizontal beta function in range from $L/2$ to $L$ to meet beam size requirements for users, to choose the vertical beta function close to $L/2$ for the installation of mini-gap undulator.

## 2 New lattice

### 2.1 Linear optics

The new version lattice of SSRF storage ring is a four-fold symmetry structure. Each super period includes five DBA cells, with one 12.0m long straight section,four 6.5m short straight sections.The main parameters of the storage ring are summarized in Table 1. Among the four long straight sections, one is used

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for installing three superconducting RF cavities, another is used for installing injection pulsed kickers and septum magnets.And other eighteen straight sections can be used to install insertion devices.

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) | 3.90 | 5.8—12 |
| Multi-Bunch/mA | 200—300 | 200—300 |
| Single-Bunch/mA | $>5$ | $>5$ |
| Straight Lengths/m | $4\times12.0$<br>$16\times6.5$ | $10\times7.24$<br>$10\times5.0$ |
| Betatron tunes, $Q_x/Q_y$ | 22.22/11.32 | 22.19/8.23 |
| Momentum Compaction | $5.2\times10^{-4}$ | $6.9\times10^{-4}$ |
| RF Frequency/MHz | 499.654 | 499.654 |
| RF Voltage/MV | 4 | 4 |
| Energy loss/Turn/MeV | 1.450 | 1.256 |
| Beam Lifetime/h | $>15$ | $>20$ |

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 is $Q_x=22.22$ and $Q_y=11.32$. The horizontal beta functions are chosen to be 10m and 3.6m, and vertical beta functions are of 6.0m and 2.5m, the horizontal dispersion functions are of 0.15 and 0.105m in the middle of long and short straight sections, respectively. The resulting lattice has a natural emittance of $\varepsilon_{\mathrm{N}}$=3.90nm·rad and the lattice functions are shown in Fig. 1.

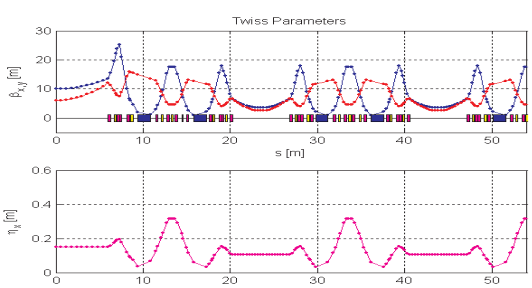


Fig. 1. Lattice functions of half super-period for ring.

Each DBA cell contains 2 bending magnets, 10 quadrupoles, and 7 sextupoles. The bending angle of each bending magnet is 9°, and its magnetic field is 1.2726T and its effective length is of 1.45m. There are total 200 quadrupole magnets in three kind of length, 26cm, 32cm and 58cm, and in ten families. The quadrupoles are powered separately and the maximum operation gradient is 20T/m. The sextupoles with the maximum gradient of 460T/m have two kinds of length, 20cm and 24cm, and they are powered in several families.

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 wide enough ranges depending on user requirements.

### 2.2 Non-linear optics

The inclusion of long straight sections: (1) changes the relative phase advance between sextupoles, (2) reduces the fold of symmetry from 20 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 storage ring with the chromaticity-correction sextupoles only (SF and SD) is very small. To enlarge the dynamic aperture, six families of harmonic sextupoles (S1, S2, S3, S4, S5, S6) are introduced in the lattice. The OPA code 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, AT[7] based on MATLAB has been used to determine the dynamic aperture.

After optimization, the horizontal on-momentum dynamic aperture in the middle of long straight section reaches 30mm and the momentum acceptance is larger than 3%. Fig. 2 shows the dynamic aperture in the middle of long straight sections of the storage ring without magnetic imperfections. The dependence of the betatron tunes upon momentum deviation is shown in Fig. 3. The tune change, up to momentum deviation of 3%, is less than 0.02 in the horizontal and 0.04 in the vertical plane.

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 $5\times10^{-4}$ and $1\times10^{-3}$, respectively. The multipole errors for dipoles, quadrupoles and sextupoles are defined in terms of ratio of the multipole field $\Delta B_n$ to main magnet field $B_N$ at a radius $R_{\rm ref}=26$mm, where $n=1,2,\cdots$, is the multipole order. The normal systematic and random rms values of $\Delta B_n/B_N$ are taken from measurement result of SPEAR3 magnets and SSRF magnets made during R&D period.

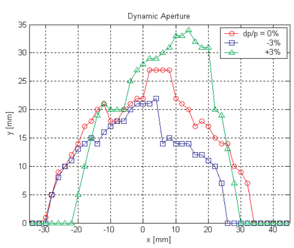


Fig. 2. Dynamic aperture.

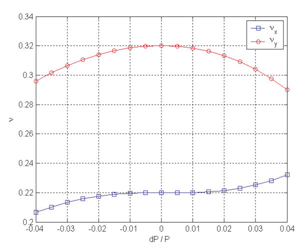


Fig. 3. Momentum dependent tune shift.

Fig. 4 shows dynamic apertures in the middle of long straight section with magnet multipole field errors tracking by using AT code. From this figure, it can be seen that the dynamic aperture is larger than 18mm, and large enough to meet the requirements for efficient injection and long beam lifetime

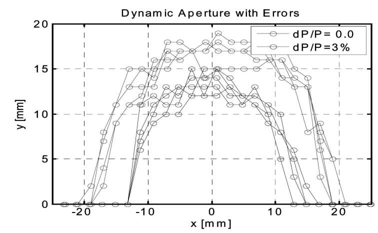


Fig. 4. Dynamic aperture with magnet's errors.

## 3 Conclusions

The performance of the storage ring can be improved by adopting distributed dispersion at straight sections in the lattice. The top-up injection is also feasible by using long straight section of 12m long. The optimised lattice has small emittance of 3.9nm. rad and enough flexibilities, the beta function and dispersion function in the middle of straight section can be changed in wide ranges depending on user needs. Tracking studies show that the lattice has large enough of the dynamic apertures and energy acceptance to meet the beam injection and lifetime requirements even with magnets multipole field errors.

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# 上海光源储存环磁聚焦结构设计*

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**摘要** 上海光源是一台正在建设中的低发射度第三代同步辐射光源. 经过优化后, 储存环有两种直线节长度, 周长432m, 在能量3.5GeV下束流发射度为3.9nm·rad, 直线节处的$\beta$函数和色散函数有足够的调节范围. 跟踪研究表明, 即使带上磁铁高阶场误差, 储存环仍有足够大的动力学孔径和能量接受度.

**关键词** 上海光源 发射度 恒流注入 磁聚焦结构 动力学孔径

*上海光源工程项目资助

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