THE SSRF STORAGE RING MAGNET LATTICE DESIGN

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Abstract

The Shanghai Synchrotron Radiation Facility (SSRF) is a 3rd generation light source with 3.5GeV in energy Its magnet lattice is composed of 20 DBA cells resulting in a ring that is about 10nm·rad in emittance and 396 meter in circumference. It provides 10 straight sections of 7.24 meter and 10 straight sections of 5.0 meter for the inclusion of insertion devices, injection components and RF cavities. In this paper, the results of linear optics design and dynamic aperture study are presented.

1 INTRODUCTION

The SSRF was proposed by the Chinese Academy of Sciences and the Shanghai Municipal Government in 1995[1]. According to the user's requirements, it should be able to provide high brightness and high flux X-ray photon beams in energy from 0.1 to 40keV. To meet this goal, the energy of SSRF has been chosen to be 3.5GeV. The SSRF accelerator complex consists of a 300MeV linac, a 3.5GeV booster and a 3.5GeV storage ring.

The 3.5 GeV storage ring is the principal component of the SSRF. Its design should be optimised to satisfy the following conditions:

1) Circumference is less than 400m,
2) Emittance is around 10nm·rad,
3) Beam current is 200~300mA for multi-bunch mode and 5mA for single-bunch mode,
4) Beam lifetime is longer than 20 hours,
5) Beam position stability is about 10% beam size at photon source points.

In the following, design of the linear optics and simulation of the dynamic aperture are reviewed.

2 LINEAR OPTICS

The performance of a Light Source, such as the SSRF, is determined primarily by the design of the storage ring magnet lattice. To meet the design goals, extensive studies have been carried out. Several possible lattices, such as the Double-Bend-Achromatic (DBA) structure [2] and the Triple-Bend-Achromatic (TBA) structure [3], have been studied. As it can meet the design goals and has a large number of straight sections for the inclusion of insertion devices, a DBA lattice has been chosen to be the basic structure of the SSRF storage ring. The storage ring consists of 20 DBA cells. Each DBA cell contains 2 dipoles, 10 quadrupoles and 7 sextupoles.

In the initial design [1] of the DBA lattice, it is a high-beta lattice with high β_x(15m) in the middle of all straight sections, and the circumference of the storage ring is 384 meter. To obtain high flux density, low β_x in some of the straight sections is required. Therefore the storage ring magnet lattice has been adjusted to be able to be operated both in high-beta mode with high β_x in all straight sections and hybrid-beta mode with high β_x in 10 straight sections and low β_x in 10 straight sections. To mach the hybrid-beta mode, the focusing quadrupole in the quadrupole triplet at both ends of the straight sections should be lengthen. And then, the circumference of the storage ring has been increased to 396 meter. The present DBA lattice provides 10 straight sections of 7.24 meter and 10 straight sections of 5.0 meter for the inclusion of insertion devices, injection components and RF cavities. Fig.1 shows the layout of one DBA cell, and table 1 lists the major parameters of the storage ring.

The new DBA lattice of the SSRF 3.5 GeV storage ring has high flexibility. The tunes and beta functions in middle of straight sections can be easily adjusted within wide range to meet the requirements of many operation modes. Four different operation modes of the storage ring, including high-beta mode with or without dispersion in straight sections and hybrid-beta mode with or without dispersion in straight sections,. have been studied. The main lattice parameters of different operation modes are given in table 2.

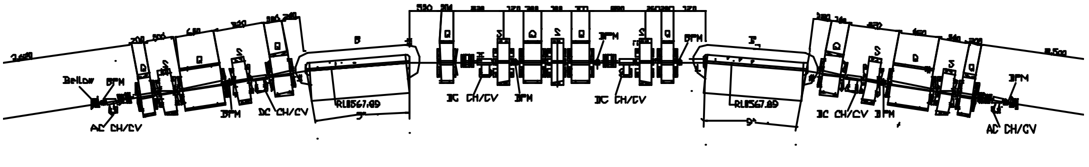

Figure 1 Layout of one DBA cell of the storage ring

Table 1 Major storage ring parameters

Operation energy E (GeV)	3.5
Lattice type	DBA
Number of cells N_C	20
Circumference C (m)	396
Straight length (m): Long straight Short straight	 7.24×10 5.0×10
Beam current I(mA): Multi-bunch Single-bunch	 200~300 5
Injection energy E_I (GeV)	3.5
Nat. emittance ε_{x0} (nm· rad)	5-12
Lifetime (hours)	>20
Harmonic number	660
RF frequency (MHz)	499.654
RF Voltage (MV)	4.0
Single turn loss U_0(MeV)	1.256
Nat. energy spread σ_E	9.23×10^{-4}
Damping time $\tau_x/\tau_y/\tau_s$ (ms)	7.35/7.36/3.68

Table 2 Summary of main parameters of different modes

Operation mode	Hybrid Beta		High Beta	
Emittance (nm· rad)	11.8	5.8	12.1	4.8
Betatron tune Q_x	22.19	22.19	18.81	18.81
Betatron tune Q_y	8.23	8.23	8.77	8.77
Momentum Compacn ($\times10^{-4}$)	6.9	4.9	6.9	7.7
Nat. chromat. ξ_x	52.8	52.8	44.2	41.2
Nat. chromat. ξ_y	24.3	24.4	23.0	23.1
Long straight η_x(m)	0.0	0.15	0.0	0.20
Short straight η_x(m	0.0	0.06	0.0	0.18
Long straight β_x(m)	12.0	12.0	12.0	12.0
Long straight β_y(m)	3.5	3.5	3.5	3.5
Short straight β_x(m)	0.9	0.8	12.0	9.0
Short straight β_y(m)	3.5	3.5	2.5	2.5

In the following, we report the design results in detail for the hybrid beta mode with non-zero dispersion in straight sections. The horizontal beta functions are 12 meter in the middle of long straight sections and 0.8 meter in the middle of short straight sections. The storage ring tunes Q_x=22.19 and Q_y=8.23 have been chosen to get low emittance, to avoid the strong resonances in the working diagram and obtain large dynamic aperture, and to provide an efficient horizontal tune for injection. Here, the dispersion is distributed in straight sections to achieve lower emittance. The resulting structure has a natural horizontal emittance ε_{x0}=5.8 nm·rad and lattice functions shown in Fig.2.

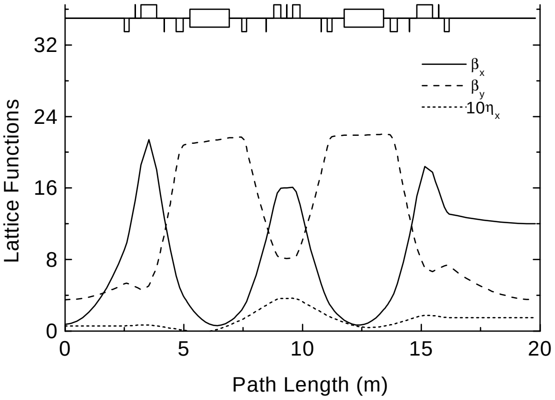

Figure 2 Lattice functions through one cell of the dispersion-distributed hybrid-beta mode

3 DYNAMIC APERTURE

For high injection efficiency and long beam lifetime, the storage ring should have large enough dynamic aperture. The dynamic aperture is determined by the nonlinear magnetic fields, such as sextupoles, magnet errors, and insertion devices.

In the SSRF magnet lattice, there are 7 sextupoles in each DBA cell (see in fig.1). Three of them (SDs and SF) are located in the arc between two bending magnets, and the others (S1, S2, S3, and S4) are equipped in the quadrupole triplets at both ends of the straight sections. For the normal operation mode with dispersion-free straight sections, SDs and SF are used for chromaticity correction to combat the head-tail instability, and the others are employed for harmonic correction to enlarge the dynamic aperture. For the low-emittance operation mode with dispersion-distributed straight sections, all sextupoles are used together for chromaticity correction and harmonic correction. Extensive studies on optimisation of the location and strength of the sextupoles for different operation modes have been carried out. It was found that the magnet lattice with asymmetry arrangement of the defocusing sextupoles SDs in the arc (see in fig.1) has large enough dynamic aperture and momentum acceptance for both the high beta mode and hybrid beta mode, and is easy to arrange the septa and kickers for injection.

Fig. 3 shows the dynamic aperture in the middle of long straight section for the dispersion-distributed hybrid beta mode without errors. The tune variations versus horizontal and vertical amplitude of betatron oscillations with 1% coupling are shown in Fig.4 and Fig.5, respectively. And the dependence of the tunes upon momentum deviation is given in Fig.6. From these figures, one can see that the horizontal on-momentum dynamic aperture in the middle of long straight section reaches 35 mm and the energy acceptance is larger than 3%. It indicates that the dynamics of the present magnet lattice without errors are good enough.

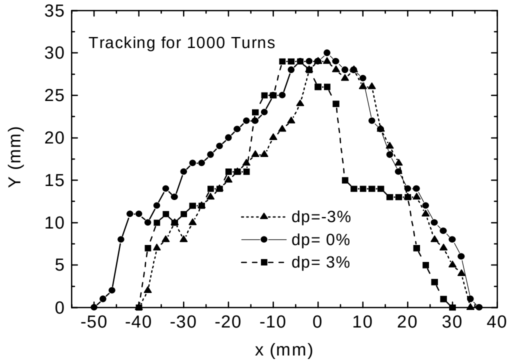

Figure 3 Dynamic aperture in the middle of long straight for the dispersion-distributed hybrid mode

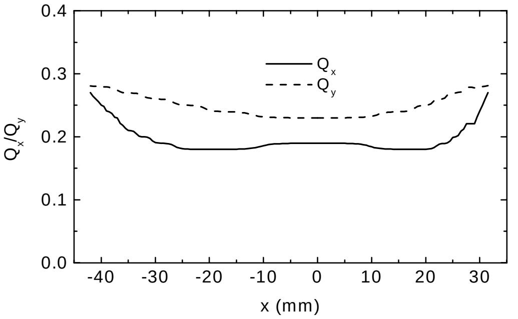

Figure 4 Tune variation versus horizontal amplitude for the dispersion-distributed hybrid mode

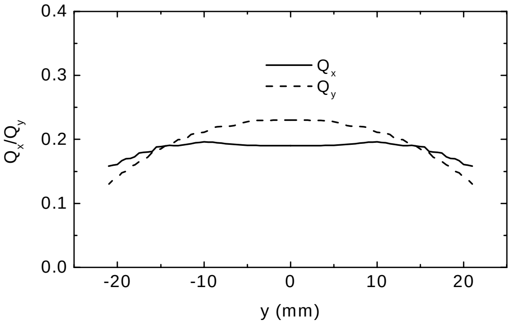

Figure 5 Tune variation versus vertical amplitude for the dispersion-distributed hybrid mode

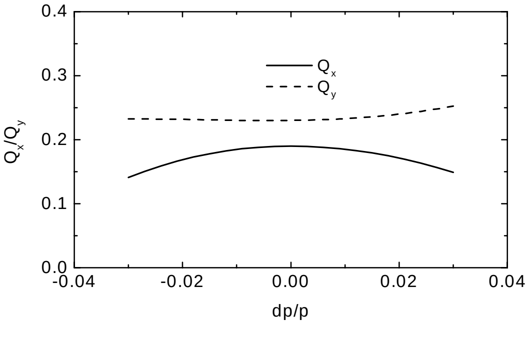

Figure 6 Momentum-dependent tune variation for the dispersion-distributed hybrid mode

The effects of systematic multipole errors and random multipole errors of magnets have been also studied. Fig.7 shows that the on-momentum horizontal dynamic aperture is larger than ±20mm in the presence of magnet multipole errors. The ±20mm aperture allows efficient capture of the booster beam injected with 15mm displacement. Fig.7 also indicates that the reduction in the dynamic aperture with ±3% energy oscillation is small than 20%. Such off-momentum dynamic apertures are large enough for long beam lifetime consideration. Moreover, studies of the insertion devices effects on dynamic aperture have been also carried out, and it was found that the magnet multipole errors dominate the ring dynamic aperture.

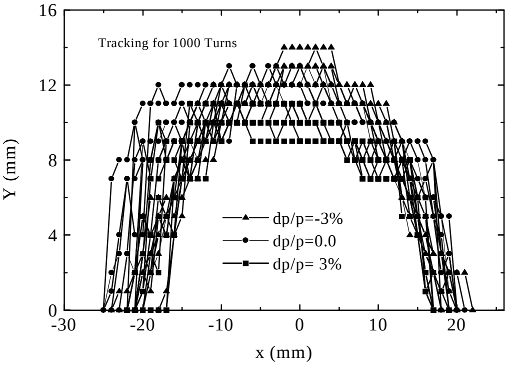

Figure 7 Dynamic aperture in the middle of long straight for the dispersion-distributed hybrid mode with magnet errors

4 CONCLUSION

This paper was based on the SSRF Conventional Design Report (Version I, 2000.5). It has been shown that the DBA lattice of the 3.5 GeV storage ring has high flexibility, and the tunes and beta functions can be easily adjusted within a wide range to meet the requirements of different operation modes, including high beta mode and hybird beta mode. Tracking studies turn out that even in presence of conservative magnetic multipole errors the dynamic aperture is adequate for injection and beam lifetime considerations.

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