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LATTICE DESIGN OF THE SSRF-U STORAGE RING

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Abstract

Multi-Bend Achromatic (MBA) cell has been well known to significantly reduce the beam emittance of the synchrotron radiation light sources in the past two decades. With the great development of the high gradient magnets, the small-aperture vacuum chamber and the precise alignment, the ultimate-emittance ring based on MBA lattice became practical in recent years. We present a preliminary lattice design for the upgraded SSRF storage ring based on a 7BA lattice in this paper. The circumference and the number of the straight sections are preserved for the existing tunnel. The beam emittance is desired toward diffraction-limited of X-ray, as much as possible.

INTRODUCTION

SSRF has been operated for users experiments since 2009. It has 13 beamlines now, and about 40 beamlines will serve users around 2020 [1]. The storage ring of SSRF has 20 DBA cells (four folds), and the beam emittance is 3.9 nm.rad on the beam energy of 3.5 GeV. In the past several years, worldwide discussion about the diffraction-limited light source of X-ray was frequently made. The beam emittance of many synchrotron light sources is designed to reach the order of 100 pm.rad, and lots of operated machines have the same upgrade considerations or plans [2]. In order to increase the photon brightness by a factor of about 100, SSRF has a preliminary upgrade plan (SSRF-U) to reduce the beam emittance by a factor of 10, reduce the beam energy to 3.0 GeV, and appropriately increase the beam current. In the following section, the lattice design of the SSRF-U storage ring is presented.

LATTICE AND BEAM PARAMETERS

The lattice of the SSRF-U storage ring is based on 7BA, because it is a good tradeoff between the emittance reduction and the cell lengthening. There are 20 cells and four folds, the same as SSRF. The upgrade ESRF-type [3] structure with beta and dispersion bump is applied due to its very effective chromaticity correction. There are only focusing quadrupoles in the arc cells, and all the defocusing gradients are provided by the combined dipoles. Six sextupoles are installed in the sections of the two beta and dispersion bumps of each cell in order to correct the chromaticity, and four harmonic sextupoles to correct the high order geometric aberrations. The maximum gradients of the quadrupole and sextupole are 80 T/m and 4000 T/m^2, respectively.

Figure 1 plots the liner optics of the SSRF-U storage ring, and Table 1 summarizes the main lattice parameters. A triplet of quadrupole beside the long straight section increase the horizontal beta function at the injection point to 25, in order that a sufficient dynamic aperture for beam injection can be obtained. The working point is optimized to be 43.22 in the horizontal plane and 17.32 in the vertical plane, and the natural emittance reaches down to 202.5 pm.rad with the beam energy of 3 GeV. Due to the IBS effect, the horizontal emittance will increase by about 37.7%, with the coupling of 10%, the RF frequency of 500MHz and the bunch current 0.4mA/bunch. A third harmonic cavity will reduce the horizontal emittance growth to 13.4%. The energy loss per turn in bare lattice is 0.44 MeV, and a RF voltage of about 2 MV can compensates the beam. The length of 5.6m of the standard straight section is left for IDs.

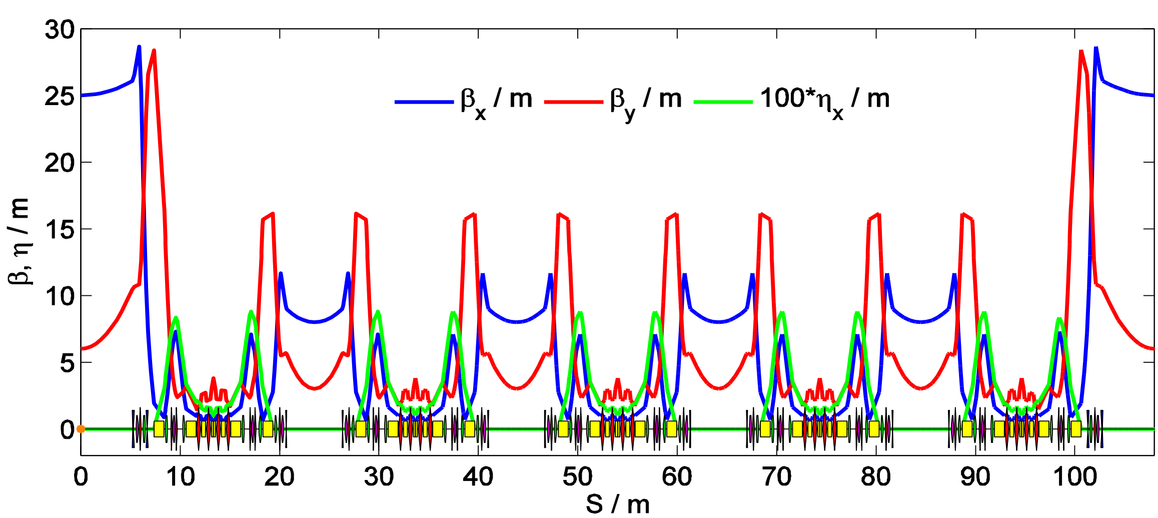

Figure 1: The linear optics of one fold of the SSRF-U storage ring.

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Table 1. Lattice Parameters of the SSRF-U Storage Ring

Beam energy / GeV	3.0
Circumference / m	432
Working point (H, V)	43.22, 17.32
Natural chromaticity (H, V)	-74.19, -59.33
Natural emittance / pm.rad	202.50
Natural energy spread (RMS)	9.2564×10^{-4}
Damping partition number (H, V, E)	2.03, 1.00, 0.97
Damping time (H, V, E) / ms	9.64, 19.59, 20.23
Radiation loss per turn / keV	441.32
Momentum compaction factor	0.00020
RF voltage / MV	2.0
RF frequency / MHz	499.654
Synchrotron tune	0.00389
Bunch length / ps	10.9550
Length of the straight section / m	16×5.60+4×10.35
β_x, β_y, η_x @ source point / m	8.0, 3.0, 0
β_x, β_y, η_x @ injection point / m	25.0, 6.0, 0

NONLINEAR BEAM DYNAMICS

There are 200 sextupoles classified into 12 families in the whole ring, and no any octupole. The dynamic aperture of on-momentum particle at the injection point is carefully optimized. Fig. 2 plots a good solution, which resulted from 6-D tracking with the radiation damping and the cavity compensation. The horizontal dynamic aperture of on-momentum particle reaches 8 mm. When there are magnetic error and alignment error, the dynamic aperture will be reduced. The new injection system based on the pulse-multipole-magnet is under design [4].

The energy acceptance is restricted to be 2% by the half-integral resonance, because of the very fast tune shift with energy deviations in the vertical plane, shown as in Fig. 3. It is ineffective to increase the vertical chromaticity. More careful study is necessary to improve the energy acceptance.

Figure 4 plots the dynamic aperture and frequency maps of the on-momentum particle. In order to get a clear resonance structure, the simulation is based on 4-D tracking, and doesn't include the radiation and cavity. The beam dynamics of the particle with high vertical amplitude is badly disturbed by some resonance node, while the horizontal plane is not serious. This behavior is benefit to the beam injection. The tune shift with amplitude is very large, and maybe the main restriction to the small dynamic aperture. It is ongoing to control the tune shit with amplitude, by the method of tune optimization, sextupole optimization, and installing octupole.

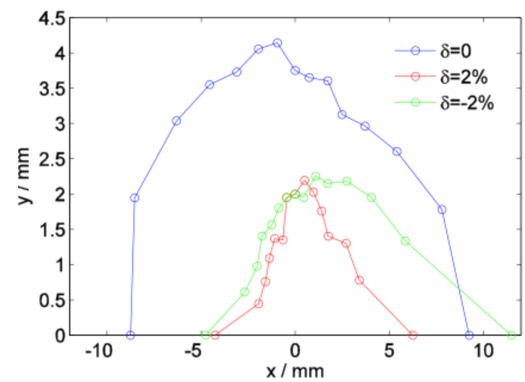

Figure 2: Dynamic apertures of the SSRF-U storage ring.

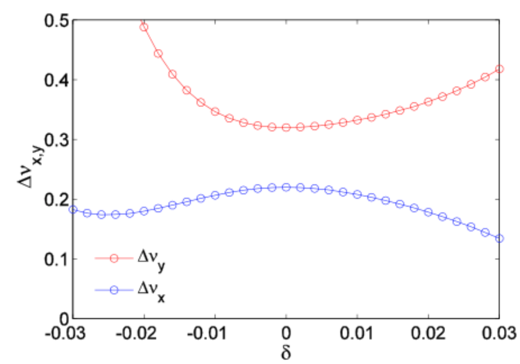

Figure 3: The tune shift with the energy deviations.

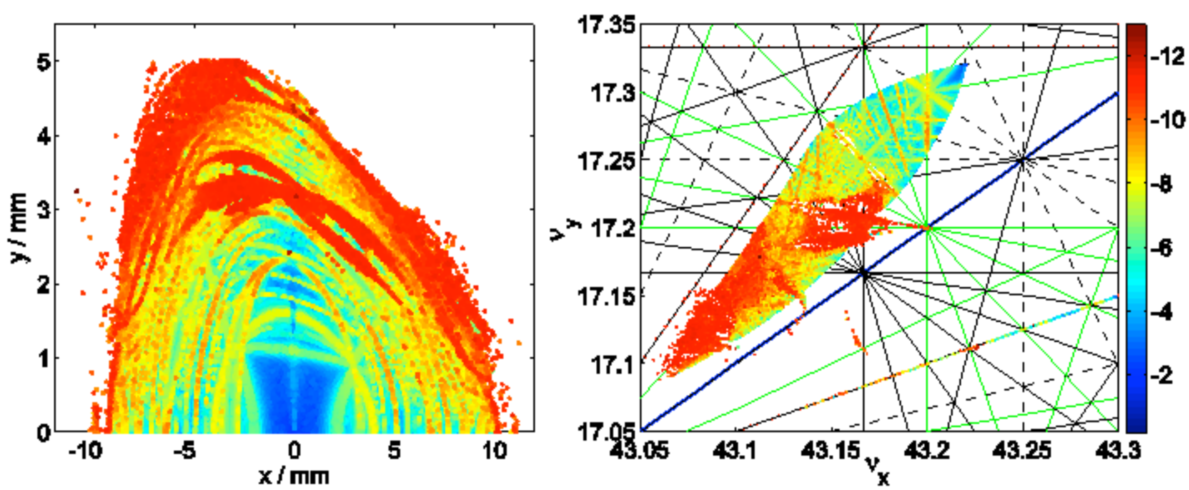

Figure 4: Dynamic aperture and frequency maps of the on-momentum particle in the SSRF-U storage ring.

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CONCLUSIONS

The designed lattice of SSRF-U matches the tunnel of the SSRF storage ring and its beamlines. The beam emittance reach down to about 200 pm.rad, and the emittance growth rate is acceptable with a third harmonic cavity. The dynamic aperture is optimized and sufficient to the beam injection based on the pulse multiple magnet.

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