Double-mini-βyoptics design in the SSRF storage ring (Postprint)

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Abstract

Shanghai Synchrotron Radiation Facility (SSRF) will implement its Phase II beamline project in the near future. Two long straight sections of the SSRF storage ring will be installed with dual-canted insertion devices in this project. Double-mini-βy optics in the long straight sections is designed and optimized in order to obtain high brightness and good machine performance. In this paper, the results are summarized. The Phase II project proposes a lattice upgrade of super-bend, and the double-mini-βy optics with this upgraded lattice is presented, too.

Full Text

Preamble

Double-mini-βy optics design in the SSRF storage ring

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Abstract: The Shanghai Synchrotron Radiation Facility (SSRF) will implement its Phase II beamline project in the near future, which includes installing dual-canted insertion devices in two long straight sections of the SSRF storage ring. To achieve high brightness and good machine performance, double-mini-βy optics in these long straight sections have been designed and optimized. This paper summarizes the results of this design work. The Phase II project also proposes a lattice upgrade incorporating super-bend magnets, and the double-mini-βy optics with this upgraded lattice is presented.

Keywords: Muon, Two-color laser, Overdense plasma, Muon sticking to alpha

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Introduction

The Phase II beamline project of the Shanghai Synchrotron Radiation Facility (SSRF) will be implemented in the near future. In this project, dual-canted in-vacuum insertion devices (IDs) will be installed in two long straight sections. To obtain high brightness and good beam lifetime with mini-gap IDs, the vertical beta function should be reduced at all source points to create a double-waist configuration. This type of optics has been implemented in many light sources, including SPEAR3 [1], BESSY-II [2], and SOLEIL [3]. Spring-8 [4] employs a unique configuration with triple-waist optics due to its very long straight sections. Because of the low symmetry and strong nonlinearity inherent in such designs, careful design and optimization are essential.

To maintain photon quality at other source points, beam parameters such as emittance and the optics outside the rearranged long straight sections should be preserved as much as possible. The reduction of the vertical beta function in the rearranged long straight sections necessarily increases the vertical tune. If these sections are rearranged without modifying any sextupoles, and the increased vertical phase advance is an integral multiple of π, the cancellation of driving terms for on-momentum particles can be maintained, preserving the original dynamic aperture. This technique is known as the "π-trick" [5]. However, several factors prevent its direct application. Unexpected nonlinear resonances may degrade the dynamic aperture for on-momentum particles, and the dynamic aperture for off-momentum particles is also crucial for beam injection and lifetime. Additionally, there are two focusing sextupoles in the rearranged sections of the storage ring, making it necessary to re-optimize the beam dynamics, including finding suitable working points and sextupole settings.

In the SSRF Phase II beamline project, it is proposed to replace eight dipoles in four symmetric cells with high-field, short-length dipoles (super-bends) to create four new straight sections [6]. This upgrade will enhance the brightness of hard X-rays emitted from the super-bends and allow installation of additional IDs. This paper presents the design and optimization of double-mini-βy optics for both the current SSRF lattice and the upgraded super-bend lattice.

[Figure 1: see original paper]. (Color online) Schematics of the long straight section with dual-canted IDs.

II. Element Arrangement in the Long Straight Sections

As shown in Fig. 1, each long straight section in the SSRF storage ring is 12 meters in length (measured as the drift between the edges of the two adjacent quadrupoles). In the Phase II beamline project, four identical dipoles of 0.3 m length will be installed to generate a canted angle of approximately 6 mrad between the two IDs. At the center, a quadrupole triplet with lengths of 0.26 m/0.58 m/0.26 m will be used to generate the double-mini-βy optics, in combination with strength adjustments of the two quadrupole triplets adjacent to the long straight section. The available space for ID installation is 3.5 meters in length.

III. Double-mini-βy Optics of the Nominal Lattice

It is necessary to verify the feasibility of double-mini-βy optics in the current lattice. In the nominal SSRF optics, the beta functions at the center of the long straight section are 10 m horizontally and 6 m vertically, with working points of 22.22 (horizontal) and 11.29 (vertical), respectively, and a natural emittance of 3.89 nm · rad. In the double-mini-βy optics, the vertical beta functions at the two source points are reduced to 1.95 m, which increases the vertical tune to 12.296. Fig. 2 shows the linear optics around the ring, and Table 1 summarizes the main beam parameters. Except for the vertical tune and the local optics in the adjusted sections, all beam parameters remain identical to the nominal values.

The SSRF storage ring contains 140 sextupoles classified into eight families according to the four-fold symmetry. In the double-mini-βy optics, this sextupole classification is maintained as in the current setting. The dynamic aperture is optimized using these sextupoles. Fig. 3 shows the dynamic aperture, frequency maps, and variations of tune and beta function as functions of energy deviation. The dynamic apertures are obtained through simulation in a realistic model that includes radiation damping, RF compensation, physical aperture of the vacuum chamber, and magnet multipole errors. The dynamic aperture for on-momentum particles reaches approximately $±$15 mm in the horizontal plane, which is sufficient for beam injection. To identify nonlinear resonances within the dynamic aperture, the model used for frequency maps excludes radiation damping. Although a severe resonance (2 + 2 = 69) is revealed in the dynamic aperture, it does not affect beam injection.

. Beam parameters of the double-mini-βy optics

IV. Double-mini-βy Optics of the Super-bend Lattice

This section presents design results for double-mini-βy optics in the super-bend lattice. The energy spread increases due to the high field of the super-bends. Since the SSRF linear optics is not dispersion-free, this increased energy spread leads to an effective emittance increase and a corresponding decrease in photon brightness. To counteract this effect, the horizontal tune must be increased by one unit to achieve lower natural emittance in the super-bend lattice. The working points in the super-bend lattice are chosen as 23.23 (horizontal) and 11.31 (vertical). Due to the stronger focusing in the super-bend lattice, nonlinear optimization becomes significantly more challenging.

To achieve sufficient dynamic aperture for beam injection, the horizontal beta function at the center of the long straight section is increased from 10 m to 16 m. In its double-mini-βy optics, the vertical beta functions at the waists in the long straight sections are set to 1.8 m, resulting in a vertical tune of 12.17 rather than 11.31. The natural emittance is 3.49 nm · rad and the natural energy spread is 0.0011. The effective emittance at the source points remains the same as (or less than) the nominal values. Fig. 4 shows the linear optics with two double-waist sections in the super-bend lattice, and the beam parameters are summarized in Table 1. Most parameter changes from the nominal to the super-bend lattice result from the super-bends themselves rather than from the double-mini-βy optics.

The eight sextupole families (two for chromaticity correction and six for harmonic compensation) are sufficient for nonlinear optimization of the nominal lattice, but additional families are required for the super-bend lattice. The sextupoles in the SSRF storage ring are re-classified: all sextupoles in the super-bend cells are grouped into four new families, the harmonic sextupoles adjacent to the double-mini-βy straight sections form two new families, and other sextupoles retain their current settings. Thus, fourteen sextupole families are used for nonlinear optimization in the super-bend lattice with double-mini-βy optics. Fig. 5 shows a good nonlinear solution where the on-momentum dynamic aperture simulated in a realistic model reaches $±$15 mm at the injection point, enabling efficient beam injection. The energy acceptance exceeds $±$3%, ensuring long beam lifetime. Frequency maps reveal that more nonlinear resonances are generated by the broken symmetry. With a resonance-free dynamic aperture, this represents the best achievable solution. Although its effects on beam injection and stability require careful study, no injected beam loss is observed in simulations.

[Figure 2: see original paper]. (Color online) Double-mini-βy optics in the nominal lattice.

[Figure 3: see original paper]. (Color online) Dynamic aperture, frequency maps, energy detuning of the double-mini-βy optics in the nominal lattice.

[Figure 4: see original paper]. (Color online) Double-mini-βy optics in the super-bend lattice.

[Figure 5: see original paper]. (Color online) Dynamic aperture, frequency maps, energy detuning of the double-mini-βy optics in the super-bend lattice.

V. Conclusion

Double-mini-βy optics have been designed and optimized for both the SSRF nominal lattice and the upgraded super-bend lattice. Four identical dipoles are used to generate the dual-canted angle, and a quadrupole triplet reduces the vertical beta function to less than 2 m. Both lattices achieve good linear and nonlinear solutions, though the sextupoles in the super-bend lattice require re-classification into fourteen families.

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