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

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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-β_y 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-β_y optics with this upgraded lattice is presented, too.

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

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I. INTRODUCTION

The Phase II beamline project of Shanghai Synchrotron Radiation Facility (SSRF) will be implemented. In this project, the dual-canted in-vacuum insertion devices (IDs) will be installed in two long straight sections. The vertical beta function should be reduced in all the source points, as double-waist, so high brightness and good beam lifetime can be obtained with mini gap IDs. This kind of optics was implemented in many light sources, such as SPEAR3 [1], BESSY-II [2], SOLEIL [3], etc. Spring-8 [4] has a unique setting, in which triple-waist optics is applied due to its very long straight section. Because of the low symmetry and strong nonlinearity, it is essential to do careful design and optimization for this kind of optics. In order to maintain the photon qualities of other source points, some beam parameters (such as beam emittance) and the beam optics outside the rearranged long straight sections should be kept as much as possible.

Due to reduction of the vertical beta function in the rearranged long straight sections, the vertical tune should be greater. If the long straight sections are rearranged without any sextupole, and the increased vertical phase advance is an integral multiple of π, the cancellation of driving terms of the on-momentum particles can be maintained, and the dynamic aperture of the on-momentum particles can be the same as the original one. This is the so called "π-trick" [5]. However, there are some facts preventing us from applying this technique. Some unexpected nonlinear resonances may degrade the dynamic aperture of on-momentum particles. The dynamic aperture of off-momentum particles is also important to the beam injection and lifetime. There are two focusing sextupoles in the rearranged sections of the storage ring. It is necessary to re-optimize the beam dynamics, including finding good working point and sextupole setting, and so on.

In the SSRF Phase II beamline project, it is proposed to replace eight dipoles in four symmetric cells with high field and short dipoles (super-bend), so as to form four new straight sections [6]. By this way, the brightness of the hard X-rays emitted from the super-bend will be enhanced, and more IDs can be installed. In this paper, design and optimization of the double-mini-β_y optics in the current lattice and super-bend lattice of SSRF are presented.

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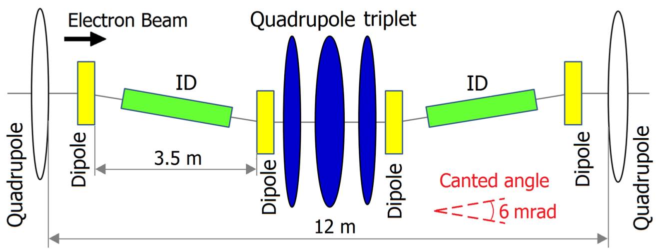

Fig. 1. (Color online) Schematics of the long straight section with dual-canted IDs.

II. ELEMENT ARRANGEMENT IN THE LONG STRAIGHT SECTIONS

As shown in Fig. 1, a long straight section of the SSRF storage ring is 12 m in length (drift between edges of the two quadrupoles). In the Phase II beamline project, four identical dipoles of 0.3 m length will be installed to generate a canted angle of about 6 mrad between two IDs. In the center, there will be a quadrupole triplet in lengths of 0.26 m/0.58 m/0.26 m, being applied to generate the double-mini-β_y optics, combined with strength adjustment of the two quadrupole triplets beside the long straight section. The space to install the ID is 3.5 m in length.

III. DOUBLE-MINI-β_y OPTICS OF THE NOMINAL LATTICE

It is necessary to check the availability of double-mini-β_y optics in the current lattice. In the nominal optics of SSRF, the β functions in the horizontal and vertical planes in the center of the long straight section are 10 m and 6 m with working

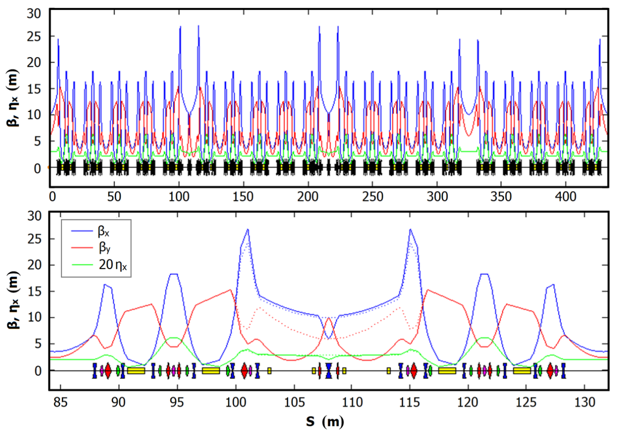

Fig. 2. (Color online) Double-mini-β_y optics in the nominal lattice.

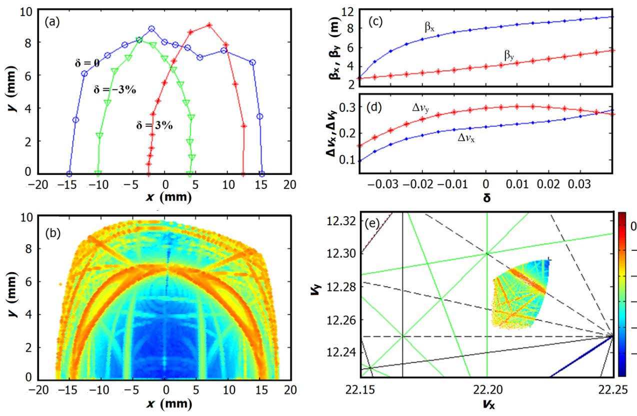

Fig. 3. (Color online) Dynamic aperture, frequency maps, energy detuning of the double-mini-β_y optics in the nominal lattice.

TABLE 1. Beam parameters of the double-mini-β_y optics

Beam parameter	Nominal lattice	Super-bend lattice
Energy / GeV	3.50	3.50
Circumference / m	432	431.9785
Working point (H, V)	22.225, 12.296	23.232, 12.170
Natural emittance / nm rad	3.84	3.49
Natural energy spread	0.00098	0.00110
Momentum compaction factor	0.00042	0.00036
Natural chromaticity (H, V)	–56.90, –18.90	–72.65, –23.34
Corrected chromaticity (H, V)	1.0, 1.0	1.0, 1.0
Damping time (H, V, E) / ms	7.09, 7.03, 3.50	6.09, 6.04, 3.01

points of 22.22 and 11.29, respectively, and the natural emittance is 3.89 nm.rad. In the double-mini-β_y optics, the vertical β functions at the two source points are reduced to 1.95 m, and thus the vertical tune increases to 12.296. Fig. 2 plots the linear optics along the ring, and Table 1 summarizes the main beam parameters. Except for the vertical tune and the local optics in the adjusted sections, the beam parameters are the same as the nominal ones.

There are 140 sextupoles in the SSRF storage ring, which are classified into eight families according to the four-fold symmetry. In the double-mini-β_y optics, the sextupole classification is maintained as the current setting. The dynamic aperture is optimized with these sextupoles. Fig. 3 plots the dynamic aperture, frequency maps, and variations of the tune and β function as a function of energy deviation. The dynamic apertures are obtained by simulation in a realistic model, which includes radiation damping, RF compensation, physical aperture of the vacuum chamber, and the magnets'multipole errors. The dynamic aperture of on-momentum particles reaches about ± 15 mm in the horizontal plane, which is sufficient for beam injection. In order to find the nonlinear resonance in the dynamic aperture, the applied model in frequency maps takes out the radiation damping. Although a severe resonance ($2\nu_x + 2\nu_y = 69$) is revealed in the dynamic aperture, it does not affect the beam injection.

IV. DOUBLE-MINI-β_y OPTICS OF THE SUPER-BEND LATTICE

In this section, we present design results of the double-mini-β_y optics in the super-bend lattice. The energy spread increases due to the high field in the super-bend. As the SSRF linear optics is not dispersion-free, the increase in energy spread brings effective emittance increase and photon brightness decrease. To counteract this increase in effective emittance, the horizontal tune shall increase by one unit to get a less natural emittance in the super-bend lattice. The working points in the super-bend lattice are chosen as 23.23 (H) and 11.31 (V). Due to the stronger focusing in the super-bend lattice, it is much more difficult to do the nonlinear optimization. In order to get sufficient dynamic aperture for beam injection, the horizontal β function in the center of the long straight section increases from 10 m to 16 m. In its double-mini-β_y optics, the vertical β functions at the waists in the long straight sections are set as 1.8 m, hence vertical tune of 12.17, rather than 11.31, the natural emittance of 3.49 nm.rad and natural energy spread of 0.0011. The effective emittance at the source points maintains the same as (or less than) nominal ones. 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. From the nominal lattice to the super-bend lattice, most changes in beam parameters are generated by super-bend, rather than double-mini-β_y.

The eight sextupole families (two for chromaticity correction and six for harmonic compensation) are sufficient for nonlinear optimization of the nominal lattice, but more families are necessary in the super-bend lattice. The sextupoles in the SSRF storage ring are re-classified: all the sextupoles in the super-bend cells are classified into four new families, the harmonic sextupoles beside the double-mini-β_y straight sections are two new families, and other sextupoles remain the current settings. So, there are fourteen sextupole families for the nonlinear optimization in the super-bend lattice with double-mini-β_y 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, and

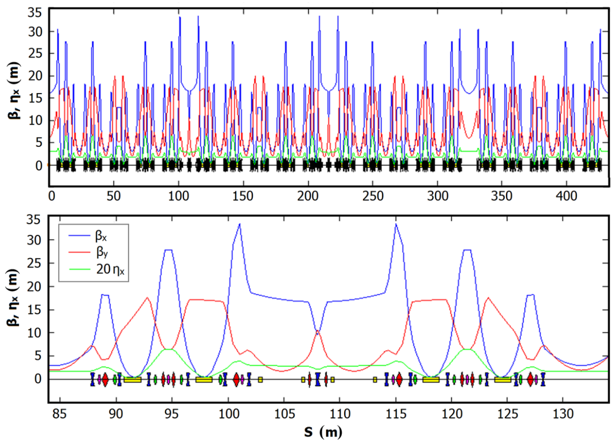

Fig. 4. (Color online) Double-mini-β_y optics in the super-bend lattice.

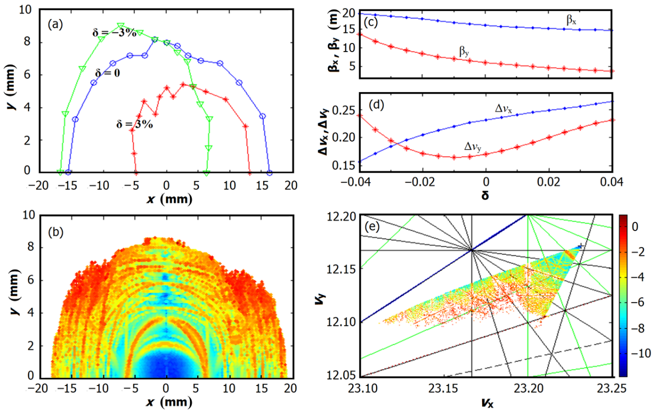

Fig. 5. (Color online) Dynamic aperture, frequency maps, energy detuning of the double-mini-β_y optics in the super-bend lattice.

this enables an efficient beam injection. Then energy acceptance exceeds $\pm 3\%$, hence a long beam lifetime. Frequency maps show that more nonlinear resonances are generated by the broken symmetry. With a resonance-free dynamic aperture, this can be the best solution. Its effects on the beam injection or stability shall be carefully studied, but injected beam loss is not observed in the simulation.

V. CONCLUSION

The double-mini-β_y optics is designed and optimized for the SSRF nominal lattice and upgraded lattice with super-bend. Four identical dipoles are used to generate dual canted angle, and a quadrupole triplet is applied to reduce the vertical β function to less than 2 m. Both lattices obtain good linear and nonlinear solutions, while the sextupoles in the super-bend lattice need to be re-classified.

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