LATTICE DESIGN OF THE SSRF STORAGE RING WITH SUPER BEND

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Abstract

Enhancement of high brightness hard X-ray production by installing higher-field, superconducting bend magnets (super bends) is proposed for the SSRF upgrade. Conceptual designs for single- and eight-superbend lattices are described here, as are the results of some preliminary studies that had the aim of maintaining machine performance.

INTRODUCTION

Users' demands for high brightness hard X-rays (20-40 keV) have been increasing in recent years. However, straight sections to install insertion devices (like superconducting wigglers for hard X-rays) are limited in many synchrotron radiation sources. It is well known that the critical photon energy emitted from dipoles increases with the bending field and the beam energy as [1]

$$\epsilon_c\ (keV) = 0.665E[GeV]^2B[T].$$

Much attention is paid to increasing the bending field and thus obtaining high brightness hard X-rays with moderate beam energy. In the early 1990s, BINP successfully fabricated and tested a superconducting bending magnet with working field of 6 T, for emitting hard X-rays in a proposed compact synchrotron radiation source [2]. The first realization of high brightness hard X-ray production with such a "super bend" was in 2001 at the ALS, which replaced three normal dipoles with superconducting bending magnets with a field above 5 T [3]. This approach has shown great availability and large beamline capacity.

As shown in Table 1, more and more synchrotron light sources implement or propose to install super bends, such as BESSY-II [2], SLS [4], DIAMOND [5], and some low-energy compact rings [6, 7]. SIRIUS [8] in Brazilian plans to add a high field slice in the centers of bending magnets in order to push the critical photon energy up to 12 keV. Light sources with a beam energy of about 3.0 GeV prefer to use room temperature bending magnets with fields of about 3 T to reach the critical photon energy of about 15 keV, and a photon energy above 20 to 40 keV is available.

The Shanghai Synchrotron Radiation Facility (SSRF) is a third generation intermediate-energy light source, which has been open for users' experiments since May 2009 [9]. Its beam energy is 3.5 GeV, and the critical photon energy from the dipoles is about 10.3 keV. If we replace a normal dipole with a super bend (B~3 T), the critical photon energy will increase to 24.8 keV. The brightness or flux of the hard X-rays from super bend will be significantly enhanced, shown as in Figure 1. We have done some preliminary study of this attractive feature; a brief scheme is presented in this paper.

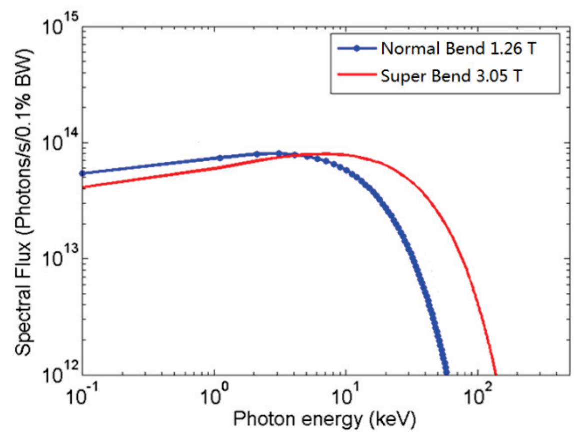

Figure 1: Photon spectrum of the normal bend and super bend in SSRF.

There are many issues and challenges in the super bend approach of SSRF. They include lattice design and beam dynamics optimization for maintaining machine performance; photon extraction in the given structure; design, fabrication, and installation of the super bend; the associated need to control errors in field and the alignment; instability of the power supply, which can induce orbit jitter and beam energy vibration; possible changes to the vacuum system; and increase of the beam

Table 1: Light sources with present or proposed super bends. SC: Superconducting magnet; RT: Room Temperature magnet, PM: Permanent Magnet; NB: Normal Bend, CJSR: Central Japan Synchrotron Radiation facility

Light source	ALS	BESSY-II	SLS	DIAMOND	SIRIUS	BINP	CJSR
Beam energy / GeV	1.9	1.7	2.4	3.0	3.0	1.2	1.2
Circumference / m	196.8	240	288	561.6	~460	<60	72
Super bend field / T	5.0	8.5	2.9	3.0	2.0	8.5	5
Super bend number	3	4	3	1 proposal	~20	6	4
Super bend type	SC	SC	RT	RT	PM	SC	SC
Critical photon energy / keV	12	16.3	11.1	18	12	8.1	4.8
NB field / T	1.3	1.53	1.4	1.4	0.5	1.65	1.4
Crit. energy from NB / keV	3.1	3.7	5.4	8.4	3.0	1.6	1.34

energy loss and the supporting capacity of the RF system. This paper presents some results about the lattice design and beam dynamics; much other work requires careful analysis in the future.

Another unique approach is replacing two normal dipoles with two super bends in one double-bend achromat (DBA) cell; thus the center of the cell will be released for use as an additional straight section for an insertion device, as in the SOLEIL lattice [10]. This approach is also discussed in this paper; much further serious study is needed.

SINGLE SUPER BEND LATTICE

The length of the normal dipole of the SSRF storage ring is 1.455 m. If we want to install a super bend with about 3 T field, the length of the super bend should be 0.6 m, and the exact bending field is 3.0543 T.

This section presents some results for the case where only one normal dipole, in the central DBA cell of a super-period in the whole ring, is replaced by a super bend. Figure 2 shows the lattice change in this DBA cell when the locations of other magnets are unchanged.

The ten quadrupoles in this cell are individually adjusted for optics matching. The matching maintains all the linear optical parameters outside of this cell unchanged, including beta, eta, and phase advances. Phase advance in this DBA cell is matched to be equal to other standard cells (keeping the working point unchanged).

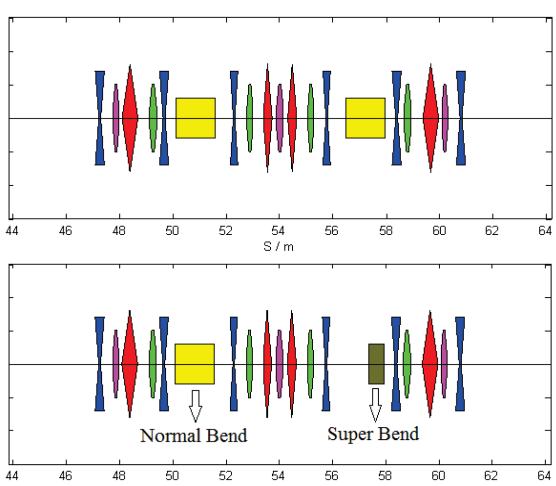

Figure 2: A single-super bend lattice compared to the nominal one.

Figure 3 plots the linear optics in this cell. Although there is a great of optimization possibility, this simple consideration is acceptable, as shown by the following results. Table 2 summaries the main beam parameters of the single super bend lattice. The natural emittance and the energy spread increase a little. The effective emittance along the ring increases by 5% with respect to the nominal optics, as shown in Figure 4. The sextupoles are re-optimized. Degradation of the dynamic acceptance is relative to the symmetry broken. However, the results are acceptable, as shown in Figure 5.

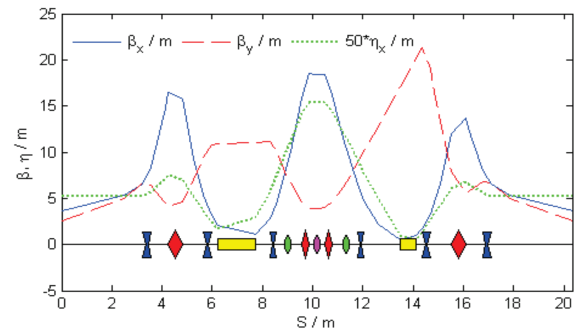

Figure 3: Linear optics in the cell with super bend

Table 2: Beam parameters of the single super bend lattice

Parameter	Value
Tune (H, V)	22.22, 11.29
Natural emittance / nm.rad	4.07
Natural chromaticity (H, V)	-55.54, -18.11
Beam energy loss per turn / MeV	1.4862
Momentum compaction factor	4.19×10^{-4}
RMS energy spread	0.001

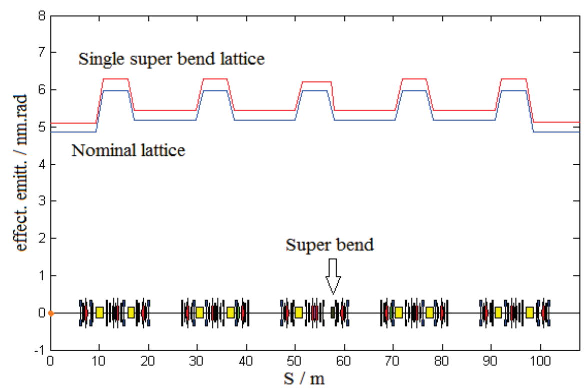

Figure 4: Horizontal effective emittance comparisons between the single-super bend and the nominal lattice.

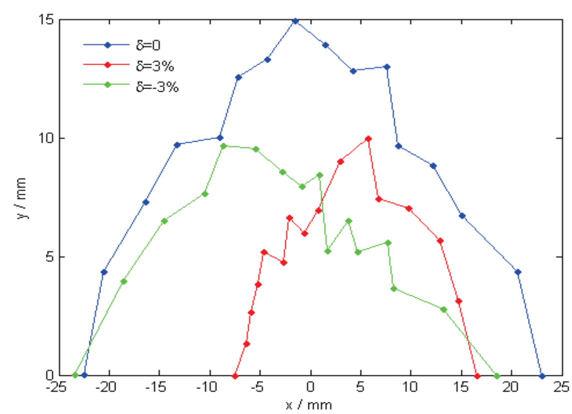

Figure 5: Dynamic apertures of the single-super bend lattice.

EIGHT-SUPER BEND LATTICE

If the two dipoles in one DBA cell are all replaced by super bends, and the arc magnets are shifted beside the super bends, there is an additional straight section of about 2 m, as shown in Figure 6. This straight section can be equipped with a short ID. In this section, we

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discuss the eight-super bend lattice, which replaces the four central DBA cells with super bends.

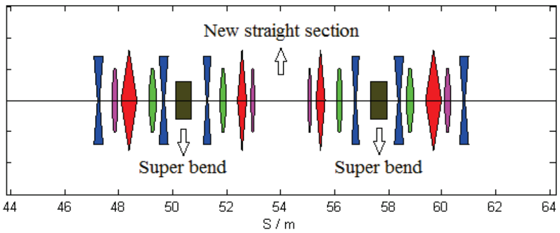

Figure 6: Lattice change of the central cell per superperiod.

At first, the same process with the single super bend lattice is carried out in this lattice, but the natural emittance increases up to about 5 nm·rad. Due to the large energy spread and the natural emittance, the effective emittance increases by about 40% with respect to the nominal optics. After the horizontal tune is increased by one unit, the natural emittance can be reduced to 3.33 nm·rad, and the effective emittance along the ring isn't higher than the nominal one. Table 3 and Figures 7 and 8 show these results.

Table 3: Beam Parameters of Eight-Super Bend Lattice

Parameter	Value
Tune (H, V)	23.22, 11.29
Natural emittance / nm.rad	3.33
Natural chromaticity (H, V)	-75.18, -21.69
Beam energy loss per turn / MeV	1.844
Momentum compaction factor	3.63×10^{-4}
RMS energy spread	0.00122

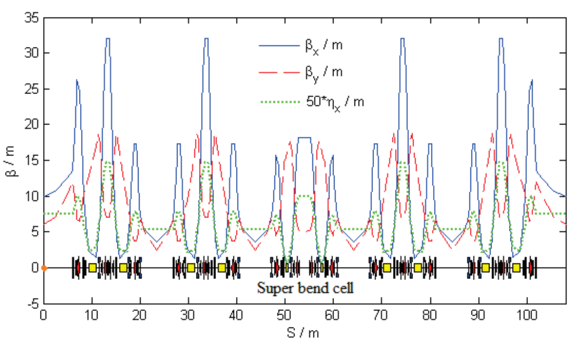

Figure 7: Linear optics in one superperiod.

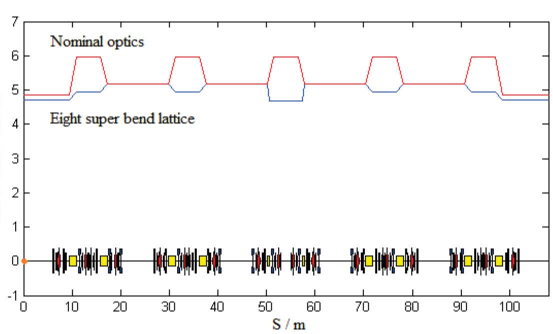

Figure 8: Horizontal effective emittance of the eight-super bend lattice and the nominal one.

The sextupoles are also re-optimized, and the dynamic aperture is reduced to ±15 mm as shown in Figure 9. However, there will be not any difficulty with efficiently injecting beam.

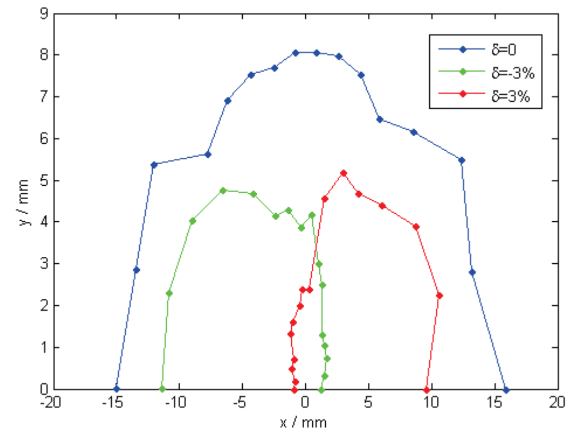

Figure 9: Dynamic apertures of the eight super bend lattice

CONCLUSIONS

The super bend with a field of about 3 T in SSRF reaches critical photon energy of 24.8 keV, and high brightness hard X-rays covering 20 to 40 keV are available. In the single-super bend lattice, the beam parameters have few changes. In the eight-super bend lattice, the machine performance, especially the effective emittance, can be maintained after re-optimization. Further studies about the lattice and beam dynamics are ongoing. Resolving other issues concerning super bend implementation is in planning.

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