THE HMBA LATTICE OPTIMIZATION FOR THE NEW 3 GeV LIGHT SOURCE

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Abstract

The HMBA (Hybrid Multi-Bend Achromatic) lattice was originally developed at the ESRF for the upgrade project of 6 GeV storage ring [1]. Based on the 20 cell version of HMBA lattice [2], we designed a 3 GeV, 130 pm·rad emittance storage ring including 20 long and 20 short straight sections. In this paper, we will report on the optimization of the HMBA lattice for a new 3 GeV light source.

INTRODUCTION

The storage ring based light source can produce photon beams with high flux and high brightness simultaneously. The flux mainly depends on the beam current and the brightness the beam emittance. The lower emittance storage ring has higher brightness. With the high brightness, the user experiments can be improved in the spatial resolution, the energy resolution and the coherent fraction. The users' requirements are the beamlines of the numbers more than forty with both high flux and high brightness photons from VUV/SX (Vacuum Ultra Violet/Soft X-ray) to HX (Hard X-ray). Adopting the HMBA lattice, the horizontal natural emittance can be reduced by more than one order of magnitude from usual third generation light sources of DBA (Double-Bend Achromatic) or TBA (Triple-Bend Achromatic) lattice structure. The brightness can be improved by almost two orders of magnitude from usual DBA light sources and by almost four orders from the present PF ring [3]. With the short straight sections newly inserted into the normal cell, the capacity of the beamline can be doubled. In this paper, we show the characteristics and performances of 3 GeV HMBA storage ring with the additional short straight section.

OPTIMIZATION OF THE LATTICE

Advantage of the HMBA Lattice

The HMBA lattice is the combination of the advantage of DBA lattice and minimum emittance MBA (Multi-Bend Achromatic) lattice (Figure 1).

Usually, DBA lattice has the large dispersion section where the chromatic sextupoles are installed. The strength of the sextupole can be suppressed thanks to the large dispersion, and the wide dynamic aperture can be realized. The emittance of the DBA light source is usually about 1~10 nm·rad. On the other hand, the emittance can be reduced to about 0.1 nm·rad with the combination of MBA lattice and combined function magnets. The strongly focused optics result in large chromaticity and small dispersion. The required chromatic sextupoles are huge and the dynamic aperture is usually small.

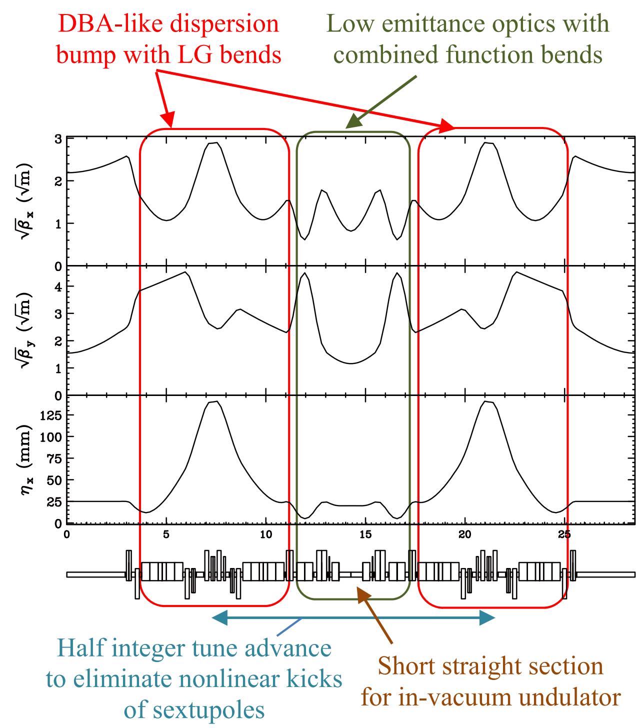

Figure 1: Optics of the normal cell of the optimized HMBA storage ring.

The HMBA lattice consists of MBA-like structure inserted between two DBA-like structures (dispersion bumps). In order to suppress the deterioration of the natural emittance, the bending magnet on either side of the dispersion bump has longitudinal gradient. As the dispersion increases, the magnetic field should reduce. To keep an adequate dynamic aperture, the tune advance between two dispersion bumps is adjusted to a half integer to compensate the nonlinear effects of the sextupoles. The concept of HMBA is very simple and clear. We think HMBA could be the standard lattice for the next generation light

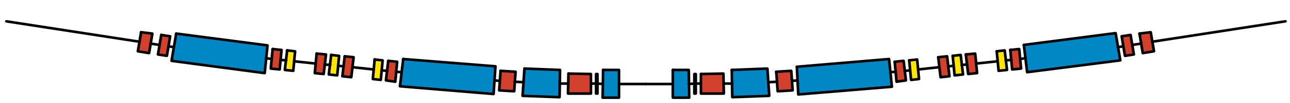

Figure 2: The lattice of the normal cell of the optimized HMBA storage ring.

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Table 1: Parameters of the Optimized HMBA Storage Ring

Parameter	Value	
Energy [GeV]	3	
Circumference [m]	570.7	
Numbers of 1.2m straight sections	20	
Numbers of 5.6m straight sections	20 (Including injection and RF)	
Numbers of cells	20	
RF frequency [MHz]	500.1	
Harmonic number	952	
RF voltage [MV]	2.0	
Bucket height [%]	4.0	
Energy loss [MeV/rev]	0.30	
Momentum compaction	$2.2\mathrm{x}10^{-4}$	
Betatron tune (ν_x, ν_y)	48.58, 17.62	
Damping time (x,y,z) [ms]	29.25, 38.28, 22.63	
Beam current [mA]	0 natural	500 (with IBS)
Horizontal emittance [pmrad]	132.5	314.7
Vertical emittance [pmrad]	-	8.2
Touschek lifetime [h]	–	1.8
Energy spread x 10^{-4}	6.4	7.9
Bunch length [mm]	2.7	3.3

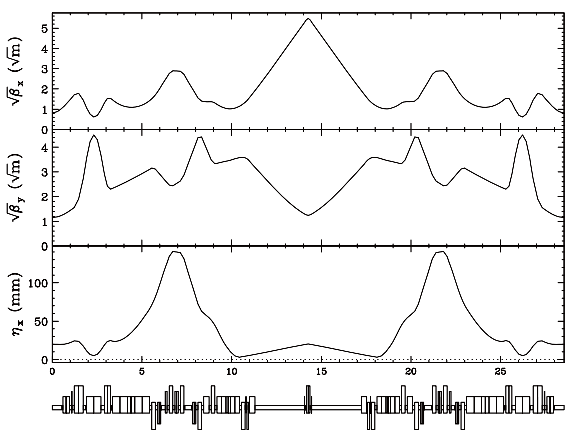

Figure 3: The optics of the injection cell for the optimized HBMA storage ring.

sources as DBA for the third generation. Indeed, many facilities in the world adopt this lattice as the base of their future projects, for example, as the Sirius project [4] and the APS upgrade project [5].

Effective Use of Short In-vacuum Undulator

For the generation of HX (10 keV) from the undulator with 3 GeV electron beam, the undulator period λ_u should be reduced to about 2 cm. The thickness of the permanent magnet for the undulator pole $\lambda_u/4$ is 5 mm. In order to make sinusoidal magnetic field on the beam axis, the gap of the undulator poles needs to be as small as the pole thickness about 5 mm. In-vacuum undulator technology which was developed in PF [6] make this configuration possible. Indeed, X-ray brightness of the PF ring has been much improved using the in-vacuum undulator of the magnetic length of 0.5 m.

In order to make the best use of the effective short in-vacuum undulators, the additional short straight section is inserted at the centre of MBA-like section of the HMBA lattice. With the strongly focused optics, the brightness of the short undulator of the total length of 0.6 m becomes more than 10^{20} that is comparable to the maximum brightness of the latest third generation light sources.

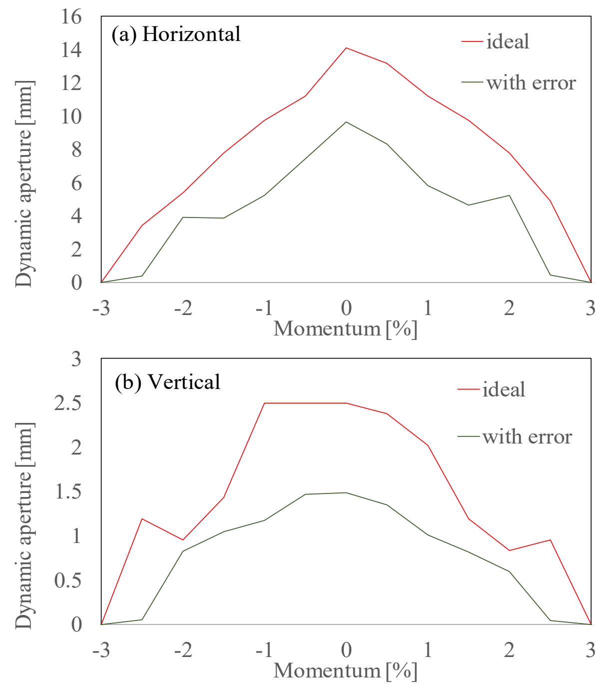

Figure 5: Dynamic aperture at the injection point with the magnetic errors after the COD correction. “with errors” shows the average of 100 cases with random magnetic errors.

Results of the Optimization

The ring consists of 19 normal cells and one injection cell. The optics of the normal are shown in Figure 1 and the lattice in Figure 2. The parameters of the ring are shown in Table 1. For the beam injection, one high β_x cell is installed to the ring. The optics of the injection cell are shown in Figure 3 and the lattice Fig. 4. Figure 5 shows the simulated dynamic aperture after the COD correction with the random magnetic errors of the alignment errors of 50 µm, field fluctuation of 0.05% and rotation of 0.1mrad. The β_x is 28 m at the injection point, and the

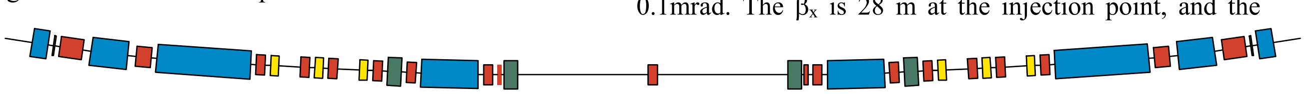

Figure 4: The lattice of the injection cell for the optimized HMBA storage ring.

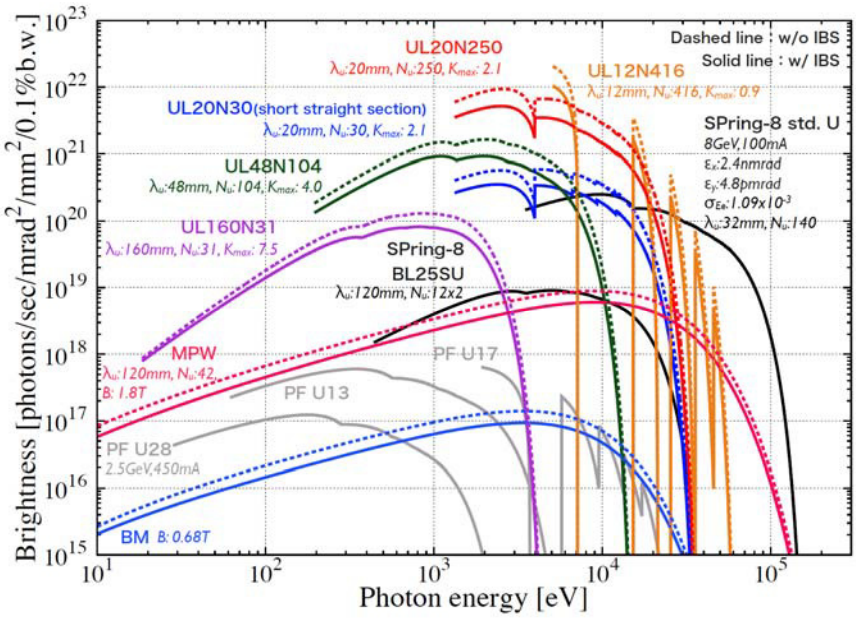

Figure 6: The brightness with typical insertion devices for the optimized HMBA storage ring compared with other existing SR facilities in Japan.

dynamic aperture is about 1 cm by considering magnetic errors. There is no problem applying the traditional injection scheme for accumulation with the stored beam size of about 0.1 mm, septum thickness about 2 mm, and injection beam size about 0.5 mm.

BRIGHTNESS

The brightness with the typical insertion devices are shown in Fig. 6. In the figure, the dashed lines show the brightness for the case without considering IBS (Intra-Beam Scattering) effect and the solid lines considering the IBS effect. The vertical emittance is assumed to be 8 pm·rad for both cases. The emittance growth due to the IBS can be suppressed with bunch lengthening by the third harmonic cavity. We began the design and simulation for IBS suppression. The brightness is about 10^{20}～10^{21} at 1 keV and 10^{21}～10^{22} at 10 keV which is higher by two orders of magnitude than those of present 3rd generation light sources and by four orders from PF.

HARDWARE DESIGN

The detailed hardware design is just started. For the strong focus to achieve the low emittance, the maximum field gradient of the quadrupoles is twice larger than PF and about 50 T/m. In order to avoid the saturation effect, the magnetic bore diameter is determined to be 3 cm. The vacuum system is required to deal with the concentrated SR power and to overcome small conductance. With the longer damping time and smaller revolution frequency, the beam instability suppression becomes a serious subject. The effects of the HOM of the RF cavities and the impedance of the narrow vacuum components have to be carefully taken into consideration. In addition to the suppression of the impedance and HOM, it is estimated that the bunch by bunch feedback system is indispensable. The third harmonic cavity is planned to be introduced for the improvement of the lifetime, brightness and the beam stability.

Typical electron beam sizes are 50 μm for the horizontal direction and 5 μm for the vertical. In order to secure the beam position stability, local mechanical vibration sources with higher frequency (e.g. air conditioner, vacuum or water pumps, chillers…) should be carefully isolated from the storage ring and beamlines. The magnetic girders which do not amplify the ground oscillation are essential. The fast and precise beam orbit feedback systems are also required.

Essentially, we can push forward necessary R&D for the new light source based on the established accelerator technologies.

SUMMARY

3 GeV, 130 pm·rad emittance storage ring with 20 long and 20 short straight sections is designed as the new light source. The dynamic aperture at the injection point is about 1cm with reasonable magnetic errors after COD correction (simulation). The traditional injection scheme can be applied and the Touschek lifetime can be acceptable by combined with the top-up injection.

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