NEW HMBA LATTICE FOR PF-AR

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Abstract

Photon Factory Advanced Ring (PF-AR) has been operated for users about 30 years from 1987. The lattice and optics are almost not changed from the original one as the TRISTAN booster ring constructed in 1984. The lattice employs FODO structure and the horizontal emittance for the 6.5 GeV user run is about 300 nmrad. In order to improve the performance of PF-AR dramatically, the full replacement of the accelerator to the ESRF type HMBA (Hybrid multi bend achromat) lattice is examined. In order to geometrically fit the new lattice to the present PF-AR tunnel, the new ring consists of 12 cells with four long straight sections. The emittance is improved to about 500 pmrad at 3 GeV. With the present user experimental hall at the northern half of the ring, at least eight undulator beam lines can be constructed. The simulated dynamic aperture is about 1.5 cm at the long straight section with reasonable magnetic errors and COD correction. The Touschek lifetime is about 6 hours. The beam injection with conventional injection system is no problem and the beam lifetime is long enough.

INTRODUCTION

HMBA lattice is developed for the ESRF EBS project [1]. The design concept of ESRF type HMBA, the normal cell has two dispersion bumps by the bending magnets with small curvature and longitudinal gradients. The chromatic sextupoles are only installed to this section where the effective chromaticity correction can be made by large dispersion function. The combined function bending magnet with defocusing field at the centre of the cell can keep emittance small. In order to suppress the non-linear effect of the sextupoles, the tune advance between two dispersion bumps is fixed at the half integer. The original lattice has very small amplitude and momentum dependent tune shifts and the large dynamic apertures. In addition, HMBA has great flexibility. For example, the 3 GeV EBS lattice of 20 cells [2] was the starting point for KEK-LS and the short straight section of 1.2 m length was added to the original lattice [3]. If we add the quadrupoles for the straight section, the performance is improved in the aperture and lifetime [4]. Since KEK-LS is fully new facility project, the replacement of existing ring is also possible by HMBA type lattice. In this presentation, we show the design and performance of the lattice replacement study by HMBA type for PF-AR.

PRESENT STATUS OF PF-AR

PF-AR is 6.5 GeV synchrotron radiation (SR) light source dedicated to the single bunch operation. The ring originally constructed as an accumulation ring (AR) for TRISTAN project in 1984. Because KEKB adopts full energy injection from LINAC, AR becomes PF-AR, the full-time synchrotron radiation facility. The circumference of PF-AR is 377 m with four long straight sections. East and west long straight sections are used for RF cavities. North and south straights are originally used for detector development for TRISTAN. Presently, the insertion device is installed in the north straight section and just small accelerator components in south. Because the original injection and extraction systems are installed to the south half of the ring, the experimental hall for SR users are concentrated only in the north half of the ring.

The original beam transport line (BT) is designed for 2.5 GeV and 3 GeV injection began in 2003. Because of the hardware limitation, full energy injection is impossible. For the SuperKEKB, continuous injection is essentially required for HER and LER due to the short Touschek lifetime with low emittance and large current. In order not to prevent SuperKEKB injection, a new BT was constructed in 2017 [5]. The injection point moved from the south-east straight section to the south-west section. If a new insertion device is installed at the old injection point, a new beamline can be constructed in existing south experimental hall. The consideration for the new beamline just began. The emittance of the present FODO structure lattice is about 300 nmrad for 6.5 GeV that is about two orders of magnitude worse than those of present advanced SR facilities.

The available beamline numbers and extremely old infrastructures are the disadvantage of the PF-AR. Comparing with PF ring that is oval shape ring of 187 m circumference, the lattice upgrade is easier for PF-AR and potential improved performance is much better because of its longer circumference and tunnel shape.

REPLACEMENT LATTICE DESIGN

In order to fit the circumference, the cell number is 12. We started the design from the 12 cells symmetrical ring consisting of identical twelve normal cells with the circumference of about 330 m and the emittance of about 0.5 nmrad for 3 GeV. It is 2 nmrad for 6 GeV. The lattice and optics of the normal cell of this starting point are shown in Figure 1. We add the short straight section to double the numbers of available insertion devices.

In order to fit the ring for the existing accelerator tunnel, we adjusted the length of the straight sections of symmetrical 12 cells ring and made it asymmetrical. The required geometrical adjustments are shown in Figure 2. There are four long straight sections more than 20 m in the ring where the horizontal tune advance of the cell cannot be kept to be the same as that of the arc normal cells. The tune survey and the tune balance survey between arc cells and 20 m straight cells show that the operating point for the best dynamic aperture

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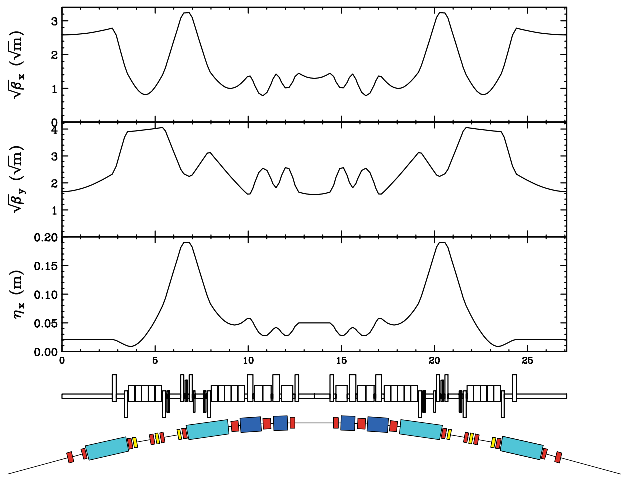

Figure 1: Lattice and optics of the normal cell of 12 cells symmetrical HMBA ring as a starting point of the design. Light blue show the bending magnet with longitudinal gradient, deep blue the combined function bending magnet, red the quadrupole magnets, and yellow the sextupole magnets. The short straight section middle in the figure is 1.6 m and the long one both sides 5.4 m.

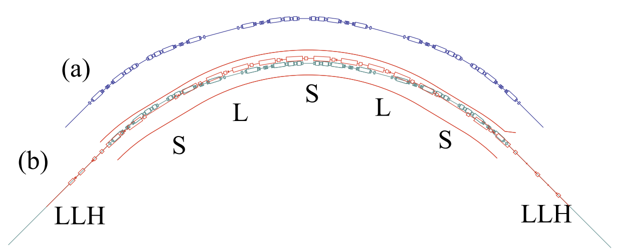

Figure 2: Geometrical adjustment of the long straight section to fit the existing tunnel arc. Figures show the quarter of the ring. The blue figure (a) is the symmetrical ring with twelve identical normal cells for the starting point of the design. The red figure in (b) shows the existing PF-AR lattice of FODO structure and the tunnel wall of the arc section. The green figure shows the new lattice for the replacement. S is the short straight section of 1.68 m, L the arc long straight of 2.7 m. LLH is the very-long straight section that has about 23 m length between two bending magnets at the both sides.

with errors is the same as the case with the complete symmetry and the tune difference should be as small as possible. To expand long straight section from 5.4 m to more than 20 m, the horizontal tune of the cell increased by 0.175 for one cell as shown in Table 1. The horizontal tune advance of LL cell is 2.3833 + 0.175 = 2.5583. To fix the total tune of the ring, the horizontal tune of the arc cell is (28.6 + 2.5583 × 4)/8 = 2.2958 . The optics of 1/8 part of the ring is shown in Figure 3. The parameters are shown in Table 2. The emittance without IBS is about 350 pmrad for 2.5 GeV, 500 pmrad for 3 GeV and 2 nmrad for 6 GeV. The potential performance seems to be great.

Assuming the magnetic errors similar to present PF ring as the Gaussian random alignment errors of 50 μm, field

Table 1: Distribution of the Betatron Tune for Geometrical Matching

		Num.	Hor.	Ver.
Symmetrical ring	Arc cell	12	2.3833	0.8417
	Total	-	28.6000	10.1000
AR fit	LL cell	4	2.5583	0.8417
	Arc cell	8	2.2958	0.8417
	Total	-	28.6000	10.1000

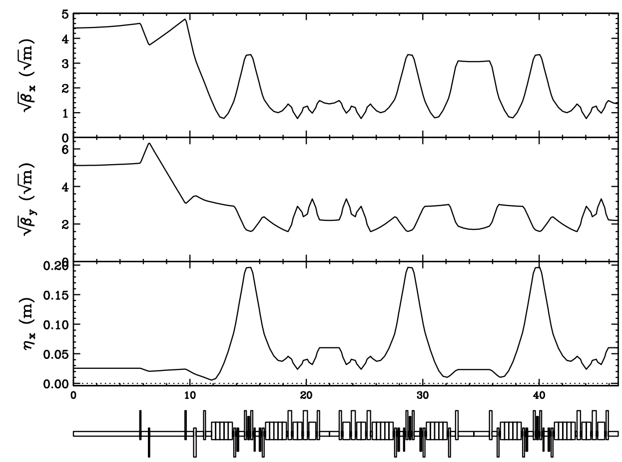

Figure 3: Optics of the 1/8 part of the ring.

Table 2: Parameters of the ring.

	Symbol [Unit]	SuperAr 3.0	
Energy	E [GeV]	3	
Cell number	N_s	12	
Circumference	C [m]	374.28	
RF freq.	f_{RF} [MHz]	500	
Harmonic Number	h	544	
Energy loss	[MeV/rev]	0.4259744	
Momentum compaction	α	5.6715×10^{-4}	
Damping time (x, y, z)	[ms]	8.365, 17.58, 19.59	
RF voltage	V_{RF} [MV]	2.5	
Bucket height	[%]	3.58	
Betatron tune (x, y)	ν	28.7, 10.2	
Beam current	[mA]	0	500
Horizontal emittance	[pmrad]	481.15	520.23
Vertical emittance	[pmrad]	-	7.8
y/x coupling	[%]	-	1.5
Touschek lifetime (3.5 % $\sigma_{\Delta p}$, 150 σ_x)	[hour]	-	5.6
Energy spread	-	9.79×10^{-4}	1.01×10^{-3}
Bunch length	[mm]	5.21	5.37

fluctuation of 0.05 %, and rotation of 0.1 mrad, the simulated dynamic aperture after COD correction is show in Figure 4. With errors, the momentum aperture is about 3.5% and the horizontal amplitude 150 σ_x. Here, σ_x is the amplitude normalized with the horizontal beam size. The dynamic aperture is large enough to adopt the conventional injection system and the estimated Touscheck lifetime is about 5.6 hours.

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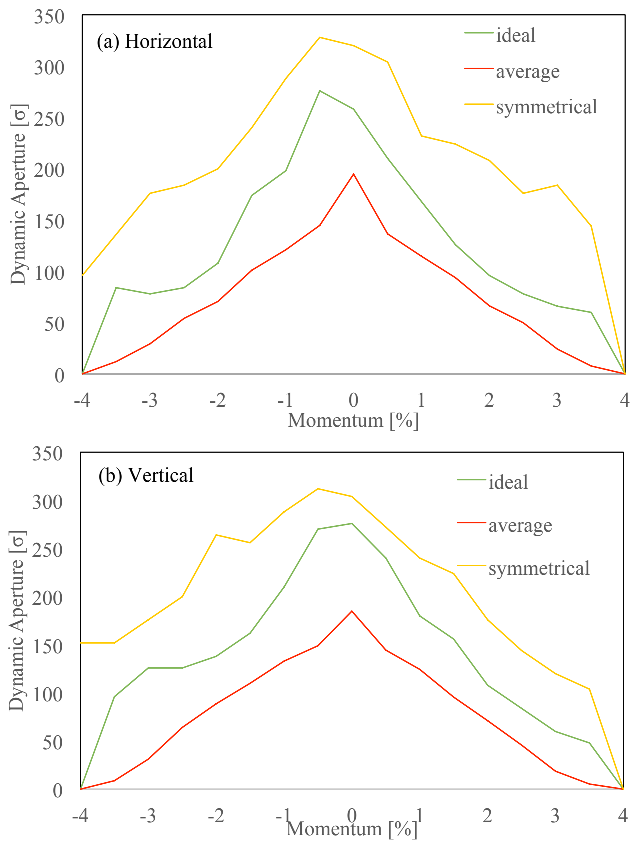
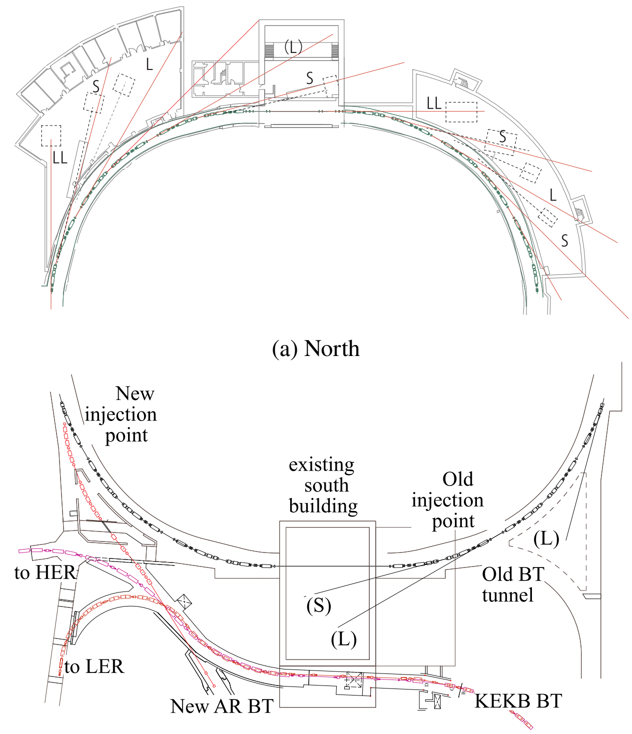


Figure 4: Dynamic aperture with reasonable magnetic errors after COD correction. The line "average" shows the averaged dynamic aperture for 100 random error seeds. The line "ideal" shows the aperture without errors and "symmetrical" for the symmetrical 12 cells case without errors.



(a) North

(b) South

Figure 5: Beamline configuration for the existing experimental hall. "LL" shows the straight line from the about 20 m (B-B) straight section at the symmetrical point of the ring, "L" 2.7 m straight section at the arc and "S" 1.68 m. (a) shows the north side of the ring and (b) south.

BEAMLINE CONFIGURATION

Because of existing KEKB BT tunnel, the experimental hall and user beamlines are presently concentrated in only north half of the PF-AR. The estimated numbers of available beam lines are eight as shown in Figure 5. Because the injection point was moved from east to west with new direct BT, the another insertion device can be installed to the old injection point and the new beam line can be constructed in the existing south experimental hall. If we can use old beam transport tunnel as the new experimental hall, another few new beamlines can be constructed.

SUMMARY

PF-AR has double circumference of the PF ring and the shape is almost the circle. The potential performance of replacement lattice seems to be great. The old infrastructures and the small space for the experimental beam line are the problem. By making the best use of new space at the eastwest side of the ring where the old BT and injection system were installed, the number of the beamlines can be increased (Figure 5 (b)).

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