LATTICE DESIGN FOR KEKB COLLIDING RINGS

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Abstract

A lattice consistent with a peak luminosity of 10^{34} cm^{-2}s^{-1} is designed for the KEK B-Factory (KEKB). A new unit cell structure with 2.5π phase advance is applied in the arc so as to install the non-interleaved sextupole pairs efficiently. This cell structure also provides a wide range of tunability for the emittance and the momentum compaction factor, while maintaining the $-I$ relation between sextupoles.

I. REQUIREMENTS FOR LATTICE DESIGN

KEKB is a double-ring asymmetric e$^+$e$^-$ collider at 3.5 GeV×8 GeV. Basic machine parameters for the goal peak-luminosity of 10^{34} cm^{-2}s^{-1} are listed in Table I. The non-interleaved chromaticity correction scheme is essential to satisfy the requirements for the dynamic aperture in KEKB. This scheme uses pairs of identical sextupoles which are connected with a $-I$ transformer in both horizontal and vertical planes. If no other sextupoles exist between paired ones, main transverse nonlinearities of sextupoles are always canceled up to the third order in the Hamiltonian.[1] Thus the transverse dynamic apertures are significantly improved.[2]

	LER	HER
Beam Energy (GeV)	3.5	8.0
Luminosity (cm^{-2}s^{-1})	1.0×10^{34}	
Half crossing angle (mrad)	11	
Tune shifts ξ_x/ξ_y	0.039/0.052	
Beta functions β_x^*/β_y^* (m)	0.33/0.01	
Beam current (A)	2.6	1.1
Bunch spacing (m)	0.59	
Particles/bunch	3.3×10^{10}	1.4×10^{10}
Emittances $\varepsilon_x/\varepsilon_y$ (m)	$1.8 \times 10^{-8}/4.3 \times 10^{-10}$	
Bunch length (mm)	4	
Momentum spread	7.1×10^{-4}	6.7×10^{-4}
Synchrotron tune	0.01∼0.02	
Momentum compaction	$1 \times 10^{-4} \sim 2 \times 10^{-4}$	
Betatron tunes ν_x/ν_y	45.52/45.08	47.52/43.08
Circumference (m)	3016	

Table I
Machine Parameters of KEKB.

II. DEVELOPMENTS IN BEAM-OPTICAL DESIGN

So far we have tried five types of optics as listed in Table II. These optics have different combinations of cell structures and chromaticity correction schemes. All optics have been designed to give the required values of the horizontal emittance ε_x and the momentum spread σ_δ. Calculations concerning lattice design such as matching of linear optics, optimization of sextupole strengths, particle tracking, etc. have been carried out with a code SAD developed at KEK.[3]

	Injection	Touschek	ν_s
I FODO Cell	bad	bad	bad
NI FODO Cell	good	fair	bad
NI π Cell	excellent	fair	good
NI 2.5π Cell	excellent	good	excellent
NI 2.5π Cell +LCC	excellent	excellent	excellent

Table II
Comparison of performances of cell structures and chromaticity correction schemes for LER. I: interleaved sextupoles, NI: non-interleaved sextupoles, LCC: local chromaticity correction at the interaction region.

We have compared the performance of these optics in the light of the following requirements: (1) to have a sufficiently large dynamic aperture for the beam injection; (2) also an enough large dynamic aperture for the Touschek lifetime; (3) to give small synchrotron tune ν_s which is necessary to avoid the synchrotron-betatron resonances caused by the lattice nonlinearities and the beam-beam effect. Since σ_δ and the bunch length have been determined, we must adjust the momentum compaction factor α_p to achieve small ν_s. Resulting performances are summarized in Table II and Fig. 1. The second criterion is especially severe for the low energy ring (LER), and thus we will discuss mainly on LER in this paper.

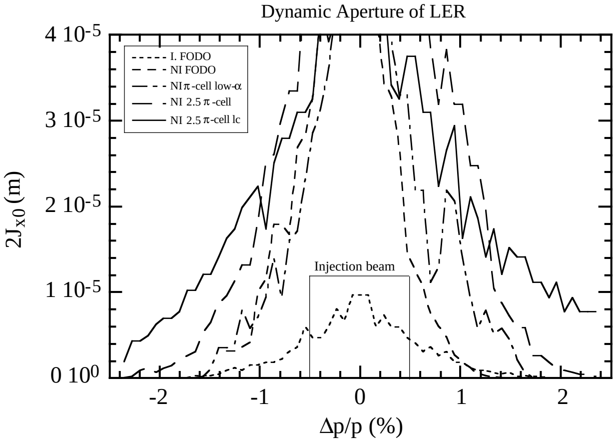

Figure. 1. Dynamic apertures of LER with five types of beam optics.

A. *Interleaved $\pi/3$ FODO Cell*

We have tried a conventional interleaved chromaticity correction scheme with $\pi/3$ FODO cells, where each quadrupole has a sextupole adjacently. Sextupoles of π phase difference are paired to cancel the lowest order of the transverse nonlinearities. Although we have tried chromaticity corrections with 6, 12, and 24 sextupole families, the dynamic aperture in all cases remains too small to satisfy the requirement. Then we have abandoned the interleaved scheme.

B. *Non-interleaved $\pi/2$ FODO Cell*

At the first step in designing arcs, we determine the bending radius ρ from the requirement for σ_δ. After fixing ρ, we need two free parameters to give required values of ε_x and α_p. In FODO cells, however, both ε_x and α_p are almost determined by the horizontal tune of the arc ν_x. If we compose arcs with $\varepsilon_x = 1.8 \times 10^{-8}$m of FODO cells, α_p becomes 4 times larger than the required. This means $\nu_s \geq 0.06$, which makes serious shrink of the operating points in the tune space. The anomalous emittance due to the chromaticity can also be serious when ν_s is high.[4] In addition, the accelerating voltage becomes too high to achieve the design bunch length. Then we have rejected FODO cells.

C. *Non-interleaved π Cell*

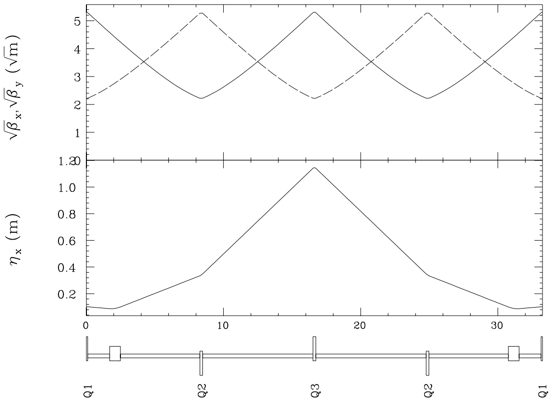

Figure. 2. Structure of the π cell for LER. The unlabeled rectangles depict dipoles.

To obtain small α_p, we must reduce the horizontal dispersion η_x in dipoles. We combine two $\pi/2$ FODO cells, merging four dipoles into two, and place the dipoles only where η_x is small, as shown in Fig. 2. We have the positions of dipoles as a free parameter as well as ν_x in this cell, thus we can decrease α_p to be small enough in the LER, keeping the required ε_x.

From the view point of the chromaticity correction, the arc built with π cells has a disadvantage that peaks of η_x are distributed only with $N\pi$ phase difference. This means that if we place sextupole pairs (SF's) for horizontal chromatic corrections only near the η_x peaks, corrections at $(N + 1/2)\pi$ phases become difficult. The packing factor of SF's becomes worse than in the FODO case. Even if we try to place SF's at small η_x points, it is still less effective for $(N + 1/2)\pi$ phases. These situations are undesirable for the chromaticity correction, then the dynamic apertures in the region of large momentum deviations are not enough satisfactory for the Touschek lifetime.

D. *Non-interleaved 2.5π Cell*

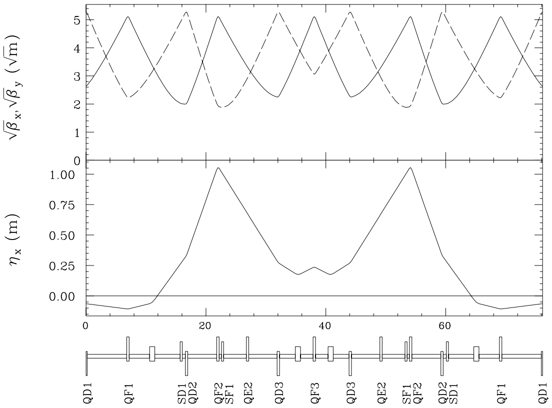

Figure. 3. Structure of the 2.5π cell for LER.

A unit cell structure with 2.5π phase advance is created by combining five $\pi/2$ FODO cells and by merging ten dipoles into four. In this cell, dipoles are placed to form two dispersion bumps so that we can keep η_x small at dipoles, similar to the π cell case. By adjusting the positions of dipoles and η_x at the dipoles, we can obtain required values of ε_x and α_p at the same time.

The 2.5π cell enables us to install non-interleaved sextupole pairs effectively. Successive SF (SD) pairs are distributed changing the relative phase of $3\pi/2$. Then chromatic kicks at $N\pi$ and $(N + 1/2)\pi$ phases in both horizontal and vertical planes can be corrected efficiently. The dynamic aperture of the 2.5π cell is significantly improved to satisfy all of the requirements. Higher-order chromaticities still remains because the sextupoles are not sufficiently close to the main chromaticity sources in the interaction region (IR). We can achieve further improvements by localized chromaticity correction in the IR.

The 2.5π cell has another merit on the tunability of ε_x and α_p. In this cell structure, we place non-interleaved sextupoles connected with a 4×4 pseudo $-I$ transformer which has $m_{21} \neq 0$ and $m_{43} \neq 0$ but basically cancels nonlinear kicks by sextupoles. We have confirmed that this pseudo $-I$ transformer brings about as a large dynamic aperture as the perfect $-I$. By allowing $m_{21} \neq 0$ and $m_{43} \neq 0$, two new free parameters become available for tuning. These parameters are utilized by placing two families of quadrupoles (QF2 and QD2) outside the sextupole pairs so that we can change them afterwards to tune α_p, keeping the pseudo $-I$ transformation. Actually we can tune α_p in the range $-1 \times 10^{-4} \leq \alpha_p \leq 4 \times 10^{-4}$ by changing the strengths of QF2's and QD2's by a few percent. During this time, ε_x is kept nearly constant.

On the other hand, it is rather difficult to change ε_x widely only by adjusting the two families of quadrupoles. To cure this restriction, we introduce a new family of quadrupoles QE2 inside the SF pair. By adjusting η_x at dipoles using five free parameters (QF2, QF3, QD2, QD3, and QE2), we can obtain the required tunability, $1.0 \times 10^{-8}\text{m} \leq \varepsilon_x \leq 3.6 \times 10^{-8}$m, while keeping α_p constant and maintaining the pseudo $-I$ condition between the SF's.

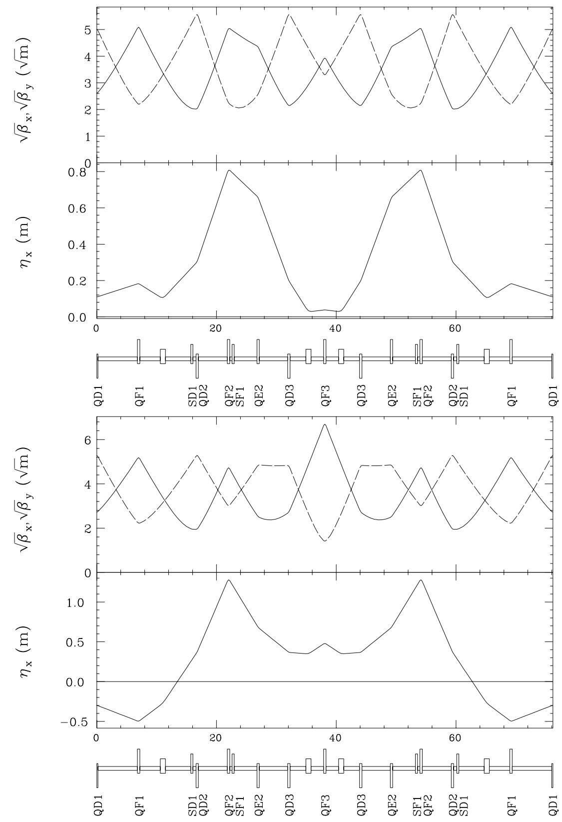

Figure. 4. Examples of emittance control in LER;1.0×10^{-8}m (above) and 3.6×10^{-8}m (below).

E. Non-interleaved 2.5π Cell with Local Chromaticity Correction

The local chromaticity correction means to correct the large chromaticity produced by the final quadrupoles within the IR. The merit of the local correction is that we can avoid producing higher-order chromaticities by the corrector sextupoles placed as optically close to the final quadrupoles as possible. Then we install the vertical sextupole pairs connected by the pseudo $-I$ transformer at the position of the phase difference $\Delta\psi_y \simeq \pi$. To install the sextupoles, we create dispersive regions in the straight section by additional dipoles and make the ratio of the functions β_y/β_x large. It is difficult to install two sextupole pairs for the correction of both horizontal and vertical planes and the locality of the horizontal chromaticity is not so large as the vertical. Thus we place only one sextupole pair for the vertical correction in the straight section in each side of the IP. The sextupole pairs at the end of the arc are used for the horizontal correction.

In designing the optics in the region of the local correction, we optimize all free parameters, that is, the lengths of drift spaces, the strengths of quadrupoles and sextupoles, to keep optical functions constant in the momentum bandwidth of 2∼3 %. The local correction has significantly improved the chromaticity correction and has also drastically improved the dynamic apertures in the region of large momentum deviations It results a factor 1.5∼2 improvement of the Touschek lifetime over the optics without the local correction.

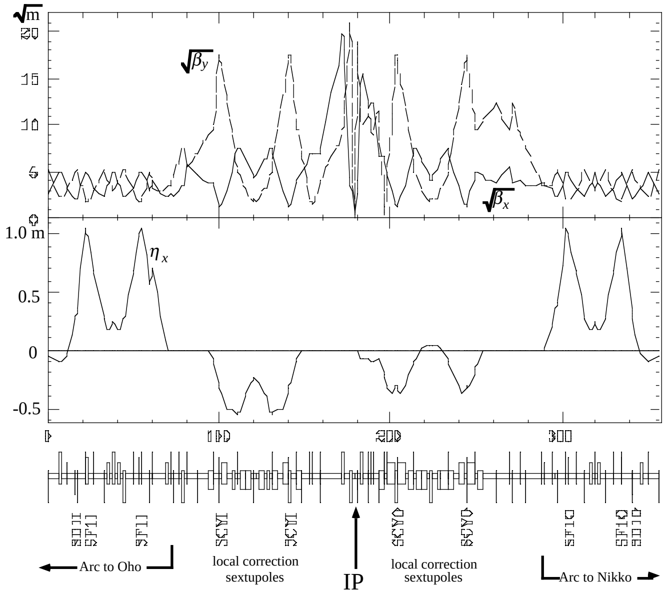

Figure. 5. Optics of the local chromaticity correction for LER. A pair of sextupoles for the vertical chromaticity correction is placed at each side of the interaction point(IP).

III. CONCLUSIONS

The lattice based on the non-interleaved 2.5π cells with the local chromaticity correction satisfies all of the requirements on the beam parameters and the dynamic apertures. Detailed study of tolerances on the dynamic aperture and the emittance ratio needs to be done.

References

[1] K.L. Brown, IEEE Trans. Nucl. Sci. **NS-26**, 3490 (1979); K.L. Brown and R. Servranckx, in *Physics of High Energy Particle Accelerators*, Proc. the Third Annual U.S. Summer School in High Energy Particle Accelerators, AIP Conf. Proc. No. 127 (1983).

[2] K. Oide and H. Koiso, Phys. Rev. **E47**, 2010 (1993).

[3] K. Oide, Nucl. Instrum. Methods **A269**, 474 (1989).

[4] K. Oide and H. Koiso, Phys. Rev. **E49**, 4474 (1994).