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Low Energy Ring Lattice of the PEP-II Asymmetric B-Factory*

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Abstract

Developing a lattice that contains a very low beta value at the interaction point (IP) and has adequate dynamic aperture is one of the major challenges in designing the PEP-II asymmetric B-factory. For the Low Energy Ring (LER) we have studied several different chromatic correction schemes since the conceptual design report (CDR) [1]. Based on these studies, a hybrid solution with local and semi-local chromatic sextupoles has been selected as the new baseline lattice to replace the local scheme in the CDR [2]. The new design simplifies the interaction region (IR) and reduces the number of sextupoles in the arcs. Arc sextupoles are paired at π phase difference and are not interleaved. In this paper we describe the baseline lattice with the emphasis on the lattice changes made since the CDR.

Parameter	Description	Value
E	Beam energy	3.1 Gev
C	Circumference	2.2 km
β_x^*, β_y^*	Beta value at the IP	50.0,1.5 cm
ϵ_x, ϵ_y	Emittance	64.3,2.6 nm-rad
ν_x, ν_y	Betatron tune	38.57,37.64
U_0	Synch. radiation	0.77 Mev/turn
τ_E, τ_x	Damping time	29.2,60.5 ms
α	Momentum compaction	1.23×10^{-3}
σ_l	Bunch length	1.0 cm
σ_E	RMS δE/E	7.7×10^{-4}

Table 1: Main LER lattice parameters

I. INTRODUCTION

The LER is the positron storage ring in the PEP-II. It is designed to operate at a nominal energy of 3.1 Gev with a range of 2.4-4.0 Gev. The ring will be newly constructed and situated 0.9 m above the High Energy Ring (HER) in the existing PEP tunnel at SLAC. It consists of six straight sections and six arcs. One of the long straight sections contains the IP with low beta optics and a local chromatic correction module. The straight section on the opposite side of the ring is configured for injection. Two other sections nearest to the IR, with one containing the RF cavities, are used for tune adjustment, and two remaining straights have optics suitable for wiggler.

The six arcs consist of cells with 90^0 phase advance. Beta bumps in the vertical plane are introduced in the two arcs adjacent to the IR to enhance the β values at the locations of sextupole pairs. Selected parameters are listed in the Table 1.

II. OPTICS

A. Interaction Region and Adjacent Arcs

The previous IR design [2] had both x and y chromatic correction sextupoles in the IR. This required two $-I$ optical modules and two beta matching sections per each half IR. This resulted in a large number of magnets in the IR and in several interference problems with the HER beam line. The new design was aimed at reducing the number of magnets in the IR.

The adopted solution was to move the local y-sextupoles from the IR to the beginning of adjacent arcs, as in the HER chromatic correction scheme [7]. This allowed to remove one $-I$ section from the IR. Due to naturally high β_x function after the final focus (FF) doublet the x-sextupole pair was left unchanged. Additionally, the number of vertical dipoles was reduced by a half to provide only one vertical separating step instead of two, and a horizontal dipole was removed after the FF doublet to provide better separation of the LER and HER beam lines. The absence of this dipole resulted in asymmetric dispersion at the local x-sextupoles, however, this did not degrade the chromatic correction. In total, the number of IR magnets was reduced by 24 magnets.

As in the CDR, each of two arcs near the IR contains two x and two y non-interleaved semi-local sextupole pairs. In the new scheme the first arc pair replaces the effect of the removed y local sextupoles and corrects primarily the linear and second order vertical chromaticity generated from the FF doublet. To optimize its effect on the vertical chromaticity, the vertical phase advance from the FF doublet to this sextupole pair was adjusted to $n\pi$ and the β_y/β_x ratio at the sextupoles was increased by introducing a local beta bump. The other semi-local sextupole families are used as additional variables to minimize the higher order chromaticity. The optics of the one half IR, including the beta bump in the adjacent arc, is shown on Figure 1.

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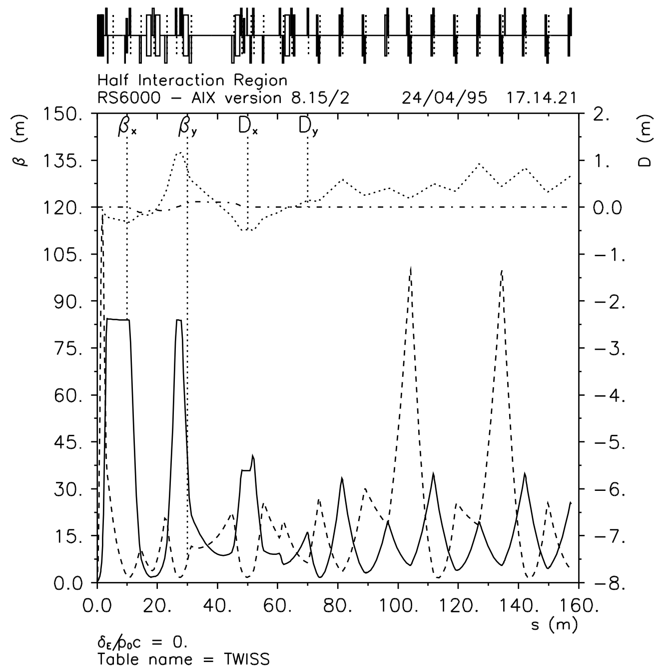

Figure. 1. Optical functions for the one half the IR.

B. *Sextupoles in Four Far Arcs*

The remaining four arcs, located remotely from the IR, are filled with global sextupoles to correct the linear chromaticity of the machine. With 90^0 per arc cell, the usual scheme of two families of sextupoles located periodically next to each F or D quadrupole has the disadvantage of generating octupole multipoles due to an interaction between interleaved F and D sextupoles. In the LER with interleaved sextupoles the resulting amplitude dependent tune shifts and fourth order resonances are one of the factors limiting the dynamic aperture.

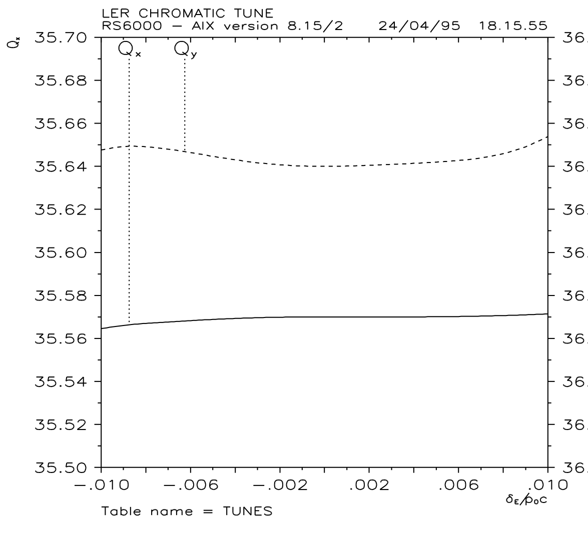

Figure. 2. Tune versus relative momentum deviation.

An alternative non-interleaved scheme was studied and adopted for the new LER lattice. It consists of four pairs of non-interleaved sextupoles per arc. Two arcs have only F sextupoles to compensate the horizontal chromaticity, and the other two arcs have only D sextupoles. The typical arrangement of four sextupole pairs is (S_1, S_1)-(S_2, S_2)-(S_2, S_2)-(S_1, S_1), where the transfer matrix between the sextupoles in each pair is $-I$ and the phase between adjacent pairs is $\pi/2$. S_2 sextupoles are as twice as stronger than S_1 sextupoles. This ratio is chosen to minimize the higher order non-linear chromaticity locally in the arcs. Additional (S_2, S_2) pairs can be added in the middle of each pattern depending on the length of the arc. The octupole-like effects in this scheme are minimal and arise only due to finite sextupole length. In this scheme the first order chromatic beta wave is locally canceled, and thus the contribution to the second order chromatic tune shift is suppressed as well. The number of sextupoles is reduced by a factor of 4 compared to the interleaved scheme, and the sextupole strength increases proportionally. Due to a less uniform sextupole distribution the overall chromatic tune shift contains larger higher order chromatic terms, but it is still adequate within the range of $\pm 10\sigma_E$. The LER tune versus relative momentum deviation is shown on Figure 2.

C. *Wiggler Straight Section*

The LER employs wiggler magnets in one straight section for beam emittance excitation and additional radiation damping. Beam emittance in the ring without wigglers is only 22 nm rad while a nominal value of 64 nm rad is required to match the beams at the IP. Moreover, emittance variation in the range of 40-100 nm rad is envisaged for the LER in order to provide flexibility of beta function adjustments at the IP and luminosity optimization.

Simulations of beam-beam effects for the condition when the damping time in the LER was about 45% larger than in the HER showed that this unbalance in damping times does not compromise the performance of the PEP-II [3][4]. This conclusion allowed us to have a much simpler variant of the LER wiggler sections than in the CDR [1]. Currently, the LER has two identical wiggler straight sections, but only one section has a wiggler. This wiggler consists of nine 40 cm length magnets and two 20 cm length end magnets with the nominal magnetic field of 1.6T. Energy loss to synchrotron radiation in the wiggler at 3.1 Gev is 130 Kev. The optics in the regions has been modified to maintain 64 nm rad nominal emittance.

D. *Other Straight Sections*

The optics in the injection region remains the same as in the CDR. The beta functions are transformed to large values by a long 90^0 cell acting as a quarter-wave transformer. Bunches are injected into the ring at the center of the straight section by using two identical kickers placed 180^0 apart in betatron phase in the vertical plane. A local DC orbit-bump is introduced to ease the requirement of the kicker magnets.

The tune and RF sections have been modified slightly to accommodate the spacing for RF cavities. These sections provide a change of the betatron tune in the range of ± 1 unit without significant change of β functions. In addition, three 120^0 cells were inserted in the middle of each section to host three families of 18 octupoles for independent adjustment of geometric tune shifts. It is known from the beam-beam effect studies [3][5] that these tune shifts can dramatically affect the beam tails.

III. DYNAMIC APERTURE

One of the important parameters of a lattice is its geometric and chromatic tune shifts. Adjustment of these tune shifts, in order to minimize the effect of lattice imperfections on a dynamic aperture, is the key to attaining a good lattice performance. For the LER, we have obtained several good lattices with very different chromatic correction schemes. Nevertheless, all these solutions have one common feature: both geometric and chromatic tune shifts are less than 0.01 at a 10σ level in amplitude or momentum.

A. Lattice Tolerances

To model the performance of the LER lattices realistically, we introduce alignment, field and multipole errors into ideal "bare" lattices. Since the CDR, alignment tolerances have been relaxed from 0.1 mm to 0.2 mm for quadrupoles and sextupoles because simulations demonstrate that the dynamic aperture and the strength of dipole correctors are still adequate after this modification. The current set of alignment parameters is presented in Table 2. We assumed that all random errors have a Gaussian distribution cut at 2σ. In general, field errors are about 0.1% for most magnets. For the final focus quadrupoles, 0.01% tolerance may be necessary.

Errors(rms)	Displacement(mm)	Roll(mrad)
Dipole	1.0	0.3
Quadrupole	0.2	0.5
Sextupole	0.2	5.0
BPM	0.15	-

Table 2: Alignment tolerances

Multipole content in the magnets is one of important factors that dominate the dynamic aperture. It is crucial that the magnets located at high beta locations have better field quality than those in the arcs. We estimated multipole errors for the magnets in the arcs based on recently refurbished and measured magnets in the HER.

B. Simulation Results

After errors are introduced into ideal lattices, we perform many commonly used procedures for correcting closed orbit, dispersion, beta beating and coupling. Typically, after the corrections the residual orbit distortion is reduced to about 0.3mm (RMS) and the vertical dispersion is down to a few cm. The beta values at the IP are controlled to be within 2% to the ideal values while the beating in the other regions is about 10%.

Finally, the dynamic aperture is determined by tracking the positrons for 1024 turns with $10\sigma_E$ synchrotron oscillations. A dynamic aperture plot at the injection point is shown on Figure 3 with the solenoid field of the detector turned off. The results for the solenoid field on can be found in Reference [6].

The damping effect was not included for tracking with 1024 turns. However, it was demonstrated that the dynamic aperture under this condition is about the same as with radiation when tracked for one damping period. The advantage of tracking without damping is a much less required computer time.

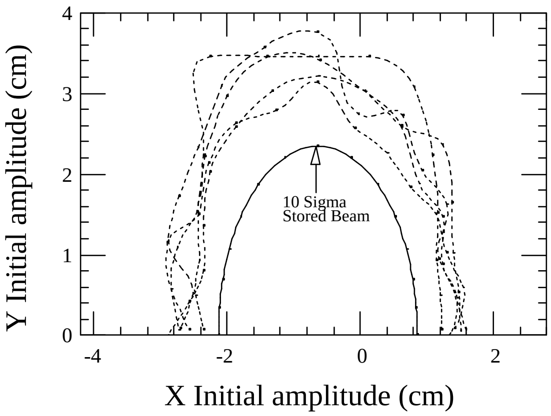

Figure. 3. Dynamic aperture for non-interleaved sextupoles and 90^0 cells, 5 seeds with full alignment and multipole errors, $10\sigma_E$ offset.

In addition, we have studied some lattices with interleaved sextupoles in the four far arcs as alternatives. In the case of 90^0 phase advance per a cell, the dynamic aperture is only about 9σ, which is largely due to the 4th order effects coherently generated by the interleaved sextupoles. For a 72^0 cell, the dynamic aperture increases to 13σ because the non-linear terms from the interleaved sextupoles do not accumulate coherently. We may use the 72^0 lattice if we need to change the momentum compaction.

IV. SUMMARY

We have shown that the new LER baseline lattice has dynamic aperture above 10σ in the presence of the realistic errors. The IR design is simpler than that in the CDR lattice. Furthermore, there is a good backup solution with 72^0 arc cells that provides momentum compaction flexibility.

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