Lattice Design for the High Energy Ring of the SLAC B-Factory (PEP-II)*

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Abstract

The design of the lattice for the High Energy Ring (HER) of the SLAC B-Factory has several special features, notably provision for octupole compensation of amplitude dependent tune shift effects and a beta-beat scheme for semi-local chromaticity correction. In the arcs adjacent to the interaction point (IP) the beta functions are enhanced to allow the use of non-interlaced sextupoles to compensate the chromaticity of the interaction region. A closed bump of beta "mismatch" is generated by two vertically focusing quadrupoles spaced 2 betatron wavelengths apart. The beta-beat has two advantages: it enhances the ratio between the horizontal and vertical beta functions at the sextupoles and, because of the locally higher beta function, allows weaker sextupoles to be used. The standard design uses a 60 degree/cell lattice but a 90 degree/cell lattice may also be used if lower emittances and momentum compaction factor are desired.

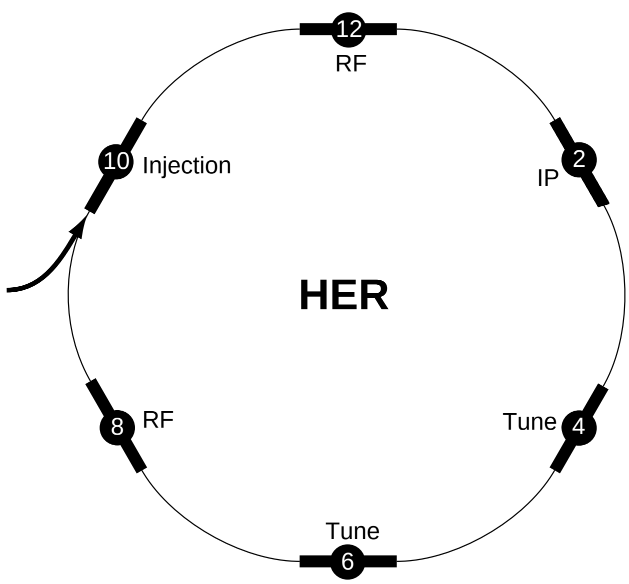

Figure. 1. Schematic of the High Energy Ring of the PEP-II B-Factory

I. INTRODUCTION

The High Energy Ring (HER) of the PEPII high luminosity B-Factory collider is an electron storage ring operating at an energy of 9-12 GeV. The arcs and straight sections are numbered like a clock, the arcs having odd numbers and the straights even numbers. The collisions with the positrons of the Low Energy Ring (LER) take place at the center of straight-2. The separation of the beams from the collision point into the separate rings is done by magnetic fields, relying on the energy difference of the counter-rotating beams[1] (The operating energy of the LER is 2.4-4 GeV). The design of both the LER and HER is described in the conceptual design report[2]. This paper concentrates on new features not described in that report.

To achieve a high luminosity, large currents of closely spaced bunches circulate in the equal-circumference rings and the beta functions at the collision point are made small. The large currents in each bunch require that the transverse emittance of the beams be moderately large to maintain a reasonably small beam-beam tune shift parameter. The magnitude of the horizontal emittance is controlled, in the LER by wiggler magnets[3] and in the HER by tailoring the dispersion function in four of the six arcs.

The low beta functions at the Interaction Point (IP), together with the longitudinal and transverse emittances, make it difficult to correct the chromaticity produced by the large beta functions at the quadrupoles adjacent to the IP. Correction of this Interaction Region (IR) chromaticity is done semi-locally in the arcs closest to the IP (arcs 1 and 3). The global (more linear) chromaticity is compensated by two families of sextupoles SD and SF in the other four arcs.

Injection is in the vertical plane using matched pulsed kickers with a $-I$ transform between them and a current sheet septum to bring the injected beam into alignment with the circulating beam. Four DC bump magnets give further control of the orbit of the stored beam. Good injection efficiency and wide momentum acceptance demands good chromatic correction at the injection point. The demands placed on chromatic correction are more stringent at injection than for colliding beam running.

The RF cavities are located in straight sections 8 and 12 and the beta functions in these areas are kept low. At the center of these straights, away from the RF cavities, are sections where octupoles may be added to control amplitude dependent tune shift effects.

The betatron tune of the HER is controlled by a series of quadrupoles in straight sections 4 and 6. A large tune range may be covered while keeping the beta functions reasonably low.

II. RF AND OCTUPOLE CORRECTION STRAIGHT SECTIONS

Provision has been made for correction of amplitude dependent tune shift effects. At the center of the RF straight sections (straight sections 8 and 12) are three regular cells that may be tuned to 60 degree/cell or 120 degree/cell phase shifts. Three families of octupoles may be placed in each of these sections to adjust the amplitude dependent tune shift terms $\partial\nu_x/\partial\epsilon_x$, $\partial\nu_y/\partial\epsilon_y$ and $\partial\nu_y/\partial\epsilon_x = \partial\nu_x/\partial\epsilon_y$. For each octupole family

*Work supported by the Department of Energy under Contract No. DE-AC03-76SF00515

there are three octupoles, one in each of the cells. The driving terms for each of the quarter-integer resonances cancel within each set for both the 60 degree/cell and 120 degree/cell cases. The octupoles of the family for adjustment of the $\partial\nu_x/\partial\epsilon_x$ term are located close to horizontally focusing quadrupoles, those for adjustment of the $\partial\nu_y/\partial\epsilon_y$ term close to vertically focusing quadrupoles and those for adjustment of the $\partial\nu_y/\partial\epsilon_x$ term are situated mid-cell. The 120 degree/cell arrangement gives better separation of the beta functions and hence more orthogonality, leading to lower strengths for the octupoles but requires stronger quadrupoles and increases the chromaticity.

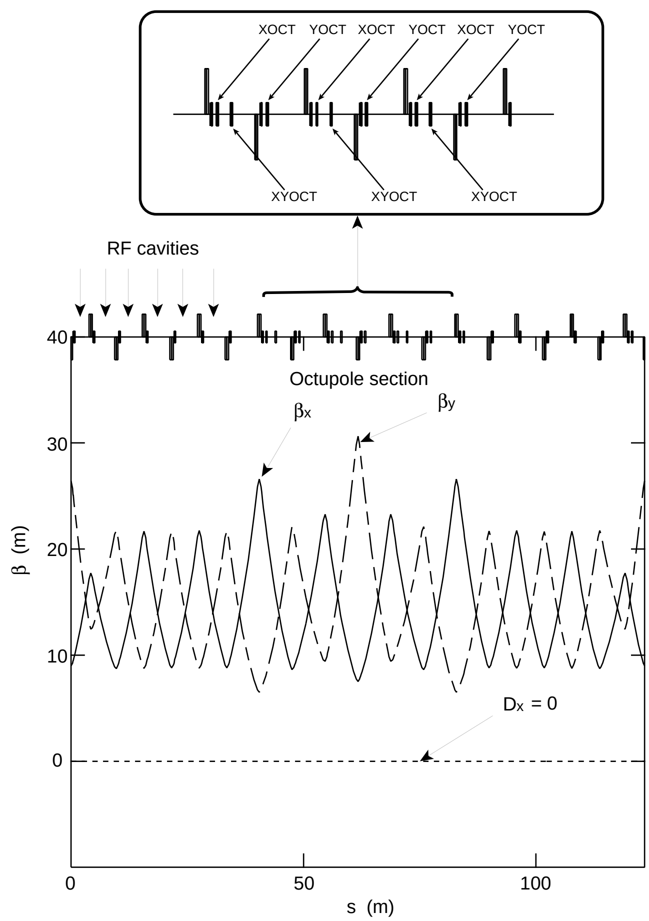

Figure. 2. Lattice functions for an RF straight section, showing positions of the RF cavities and the octupole correction section

III. CHROMATICITY CORRECTION

Initially the semi-local correction of the IR was achieved by many families of sextupoles in arcs 1 and 3. Each of the six arcs are comprised of 12 regular cells with 2 dispersion suppressor cells at each end (The dispersion suppression does encroach slightly into the regular cells). For normal operation the regular cells have a phase shift of 60 degree/cell in both planes. Sextupoles were arranged in pairs three cells apart (180 degrees) in an interleaved manner e.g. SD1,SD2,SD3,SD1,SD2,SD3,SD4... with the SF families interleaved between them.

This arrangement gave very good correction of high order chromaticity but suffered from the geometric effects of the strong interleaved sextupoles. For a β_y^* of 2 cm the dynamic aperture of the HER was adequate, but to gain improvement in dynamic aperture and to reduce the β_y^* down to 1.5 cm alternative correction schemes were investigated.

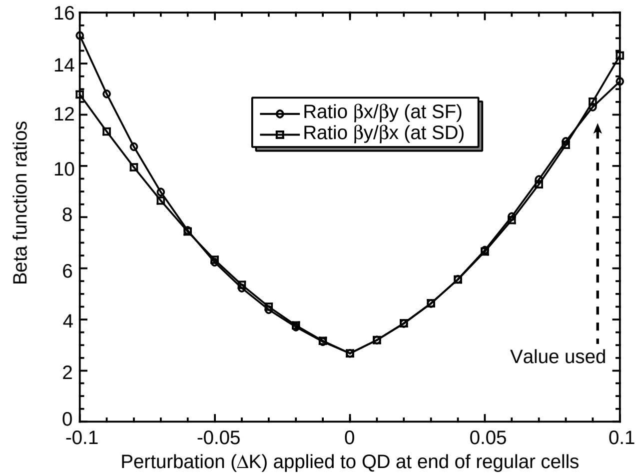

Figure. 3. The ratio of the vertical and horizontal beta functions as a function of the quadrupole perturbations.

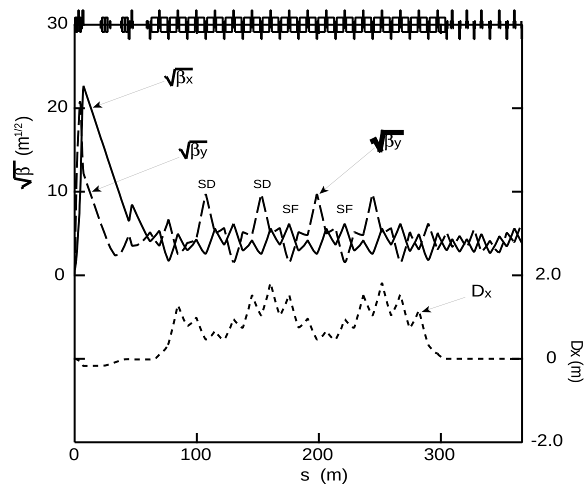

Figure. 4. Lattice functions for sextant 2-4 showing the perturbed beta functions in arc 3.

A fully-local correction scheme such as that used in linear collider final-focus schemes or that formerly used in the LER[4] was not possible because of the limited space in the IR straight and the radiation from the strong bends that would be required for such a final-focus scheme.

Non-interleaved pairs of sextupoles were tried, a pair of vertically focusing sextupoles (SD) three cells apart followed by a pair of SF sextupoles also three cells apart ($-I$ transform), the horizontal and vertical betatron phase shifts from the IP to the sextupoles being adjusted for the best results. The improvement in on-momentum performance was dramatic but the momentum bandwidth was not acceptable.

It was found that the first correction, vertical in this case, was good but caused bad performance of the second (horizontal) correction. It was deduced that the relatively small ratio of the beta functions (vertical/horizontal) was causing the problem. Cells with 90 degrees of phase shift have a better vertical/horizontal beta function ratio and allow more sets of sextupoles in those arcs. The best arrangement found was Y,X,Y correction but it still was not good enough. The sextupoles were also far too strong (due to the lower dispersion function of the 90-degree cells).

A new idea was then tried. At each end of the block of regular cells (two betatron wavelengths for 60 degree cells) vertically focusing quadrupoles were perturbed to make a region with large beating of the beta functions. A positive perturbation at one end was ended by an equal negative perturbation at the other end. The perturbation that we chose increased the beta function ratio from 2.7 to 13.

The result was enhancement of the vertical beta function in parts of the arcs at the same places as depression of the horizontal beta function, and vice versa, leading to much improved beta function ratios. Due to the higher (wanted) beta functions, where the sextupoles were placed, the strength of the sextupoles was much reduced. The perturbation of the beta functions does cause a perturbation in the dispersion function but this is not a problem. The sum of the dispersion functions at the positions of each of a pair of sextupoles is equal to that of the unperturbed cells. The chromatic effects of the sextupole pair depends (to low order) only on that sum of the dispersion functions. Choosing vertically focusing quadrupoles to make the perturbation minimizes the effect on the dispersion function.

Variations may be made on this beta-beat scheme. When implementing the scheme in a 90 degree lattice some of the enhancement of the beta ratio is lost due to the sextupoles not being at the beta minimum (at the quadrupole positions). This can be countered by making a double beta-beat, first vertical, then changing to the horizontal. There is space to do this with a 90 degree lattice since there are three betatron wavelengths in the 12-cell block of regular cells. The 90 degree cells do require much stronger sextupoles due to their lower dispersion function.

IV. PERFORMANCE OF THE CHROMATIC CORRECTION

The performance of the beta-beat chromaticity correction is much better than that using interleaved sextupoles in the arcs adjoining the IP. The synchro-betatron side-bands of the half-integer resonance $2\nu_x - n\nu_s$ are troublesome due to the imperfect correction of the high order chromaticity. Nevertheless, the performance in those regions equals that of the interleaved scheme and vastly out-performs it elsewhere in the tune diagram[5].

When magnet alignment errors and multipole errors are included in particle tracking the dynamic aperture is found to be more than adequate for both injection and colliding beam running.

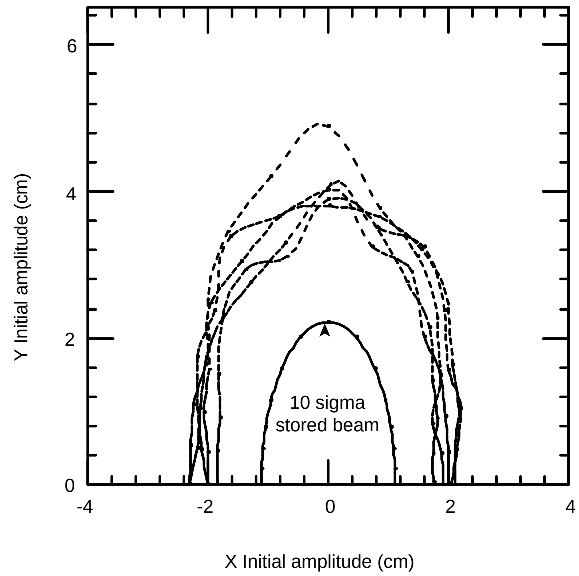

Figure. 5. Dynamic aperture of the HER using 5 seeds for alignment and multipole errors. Particles are stable for initial amplitudes within the curves shown.

V. SUMMARY

Recent improvements have been made to the design of the High Energy Ring. The dynamic aperture has been much improved, allowing for operation at a lower value of β_y^*. Provision has been made for compensation of amplitude dependent tune shifts by the use of octupole sections.

References

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[5] Y. T. Yan, *et al.*, “Swamp Plots for PEP-II Lattices,” these proceedings.