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SUPER-B LATTICE STUDIES*

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Abstract

The SuperB asymmetric e+e- collider is designed for 10^{36} $cm^{-2}s^{-1}$ luminosity and beam energies of 6.7 and 4.18 GeV for e+ and e- respectively. The High and Low Energy Rings (HER and LER) have one Interaction Point (IP) with 66 mrad crossing angle. The 1258 m rings fit to the INFN-LNF site at Frascati. The ring emittance is minimized for the high luminosity. The Final Focus (FF) chromaticity correction is optimized for maximum transverse acceptance and energy bandwidth. Included Crab Waist sextupoles suppress betatron resonances induced in the collisions with a large Piwinski angle. The LER Spin Rotator sections provide longitudinally polarized electron beam at the IP. The lattice is flexible for tuning the machine parameters and compatible with reusing the PEP-II magnets, RF cavities and other components. Details of the lattice design are presented.

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Abstract

The SuperB asymmetric e+e- collider is designed for 10^{36} $cm^{-2}s^{-1}$ luminosity and beam energies of 6.7 and 4.18 GeV for e+ and e- respectively. The High and Low Energy Rings (HER and LER) have one Interaction Point (IP) with 66 mrad crossing angle. The 1258 m rings fit to the INFN-LNF site at Frascati. The ring emittance is minimized for the high luminosity. The Final Focus (FF) chromaticity correction is optimized for maximum transverse acceptance and energy bandwidth. Included Crab Waist sextupoles suppress betatron resonances induced in the collisions with a large Piwinski angle. The LER Spin Rotator sections provide longitudinally polarized electron beam at the IP. The lattice is flexible for tuning the machine parameters and compatible with reusing the PEP-II magnets, RF cavities and other components. Details of the lattice design are presented.

INTRODUCTION

The SuperB lattice must fulfill several challenging requirements including an ultra low emittance of ≈2 nm·rad, IP vertical beam size of 35 nm, large dynamic aperture, short damping time, sufficient beam lifetime, as well as provide electron polarization at the IP. The lattice, therefore, must include the features of modern low emittance damping rings and light sources combined with an ultra low-β Final Focus (FF) with large crossing angle.

The SuperB lattice consists of two main systems:

- **FINAL FOCUS** with the Crab Waist (CW) scheme which provides the extremely low IP β-function, correction of its relative chromaticity, and the necessary conditions for the Crab Waist optics.
- **ARCs** which bend the beams back into the Final Focus IP and generate the design low emittance.

The SuperB lattice has been constantly improving since the CDR [1] (2007) towards a compact and performing design described below.

LAYOUT

The SuperB horizontal layout is shown in Fig. 1, where IP is at the top. The short ≈1258 m rings fit to the INFN-LNF site at Frascati. The HER beam direction (e+) is clockwise and the LER beam (e-) is anti-clockwise. The Final Focus is connected to the Arcs on the left and right hand sides and a long straight section at the bottom of the figure. To close the rings, a "parasitic" crossing without collisions is arranged near the left side of the long straight. The rings are horizontally separated by ≈2.1 m everywhere except near the two crossing points. The HER is on the outer side on the right side of the IP and the rings positions are exchanged on the other side.

The FF sections in the HER and LER produce the same total bending angle and ±33 mrad asymmetry relative to the IP in order to create the 66 mrad crossing angle. In this case, the left side of the LER FF is mirror symmetric to the right side of the HER FF and vice versa. This makes the FF layout symmetric with respect to the IP.

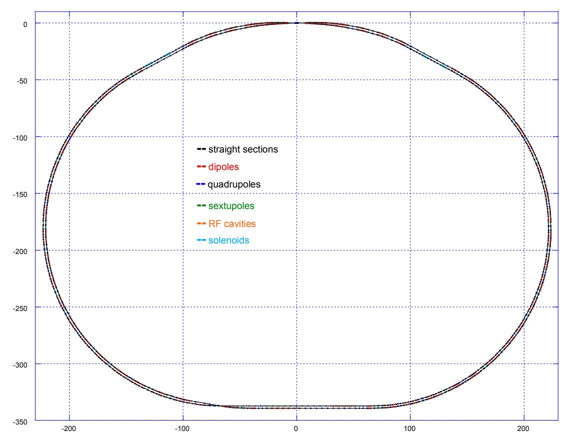

Figure 1: The SuperB layout, where IP is at the top.

ARCS

The Arcs design has improved in terms of: larger transverse dynamic aperture; larger energy acceptance; greater parameter flexibility; lower natural chromaticity; higher momentum compaction factor; higher instability thresholds; lower error sensitivities; reduced complexity.

Design of the HER and LER Arcs is practically the same. The difference is that dipoles in the LER are 3 times shorter than in the HER in order to attain a similar emittance value at the lower beam energy. Because of the two ring crossings, each ring has an inner and outer Arc. They have the same bending angle, but the outer Arc is made longer by increasing drift space around the dipoles, in order for the inner and outer Arcs to be concentric.

Each Arc consists of short and long cells, shown in Figs. 2 and 3. A TME type lattice was initially used in order to minimize the emittance, however, the standard TME cell was then modified by splitting the central dipole in two magnets and inserting a horizontally focusing quadrupole between them (see Fig. 2). This improves optics flexibility and increases horizontal focusing at the dipoles for a lower emittance. Phase

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advance in the short cell is set to near $\mu_x \approx 3\pi/2$, $\mu_y \approx \pi/2$ for optimal chromatic compensation.

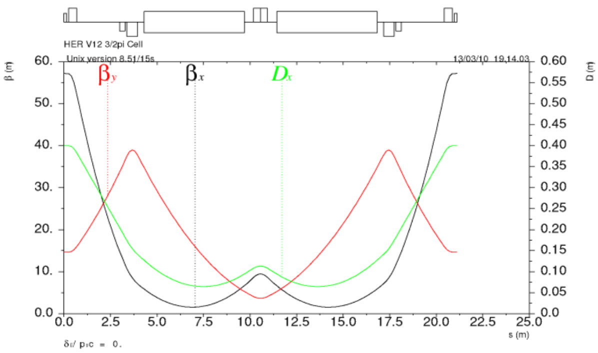

Figure 2: Lattice functions in the HER short cell.

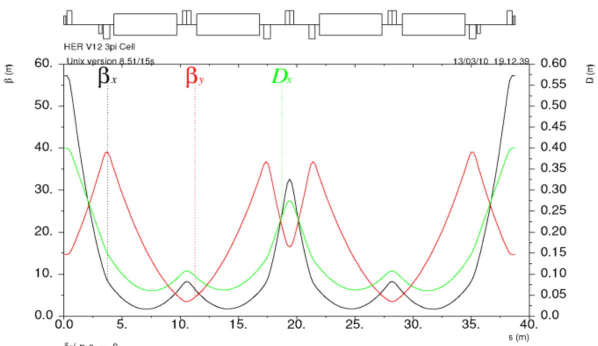

Figure 3: Lattice functions in the HER long cell.

The long cell in Fig. 3 combines two short cells into one. It uses 5 independent quadrupole families for greater optical flexibility. This helps to maximize β-functions and dispersion at sextupole locations in order to decrease their strengths and their non-linear effects on dynamic aperture. For further reduction of emittance and the 2nd order chromatic tune shift, bending angle in the dipoles near the center of this cell is reduced by 8 mrad compared to the other dipoles in the long and short cells. Phase advance is set to $\mu_x = 3\pi$, $\mu_y = \pi$ for –I transformation in both planes.

The cell horizontal phase advance must be relatively high in order to attain a low emittance. The cell vertical phase advance is chosen to be 3 times lower in order to reduce the Arc chromaticity while still preserving –I transformation in the long cell and ~π/2 transformation in the short cell. The long and short cells are arranged periodically one after the other in each Arc. A dispersion suppressor cell at each Arc end cancels the dispersion.

Arc chromatic sextupoles are inserted at the beginning and end of the short and long cells, where β-functions and dispersion are at maximum. In this scheme, the identical sextupoles form –I pairs which provide local cancellation of the sextupole 2nd order geometric aberrations and the 2nd order dispersion, leaving only the higher order terms due to finite sextupole length and partial overlap of the pairs. To minimize the chromatic W-functions and non-linear chromatic tune shift, and maximize the dynamic aperture, phase advance in the short cell has been optimized to near $\mu_x \approx 3\pi/2$, $\mu_y \approx \pi/2$.

The described Arc lattice provides safety margins on parameter specifications. For example, the Arc transverse acceptance is >100σ, whereas the physical aperture is about 40σ. A similar Arc lattice is adopted for the SuperB Damping Ring providing an excellent performance.

FINAL FOCUS

Final Focus is the most critical system for achieving the SuperB performance. It must provide an ultra low vertical beam size at the IP of 35 nm, as well as ensure full functionality of the Crab Waist optics for compensation of harmful beam-beam non-linearities [2].

The adopted FF design is based on the “Next Linear Collider” (NLC) system that had been successfully tested at the “Final Focus Test Beam” (FFTB) at SLAC, where vertical beam size of ≈70 nm had been measured [3]. Similar but somewhat simpler FF systems were used at the SLC [4] and now at the ATF2 [5]. The SuperB will have effectively four FFTB-like FF sections with the extra complication that the beams are not dumped after IP, but must remain almost unchanged after passing through both sides of the FF.

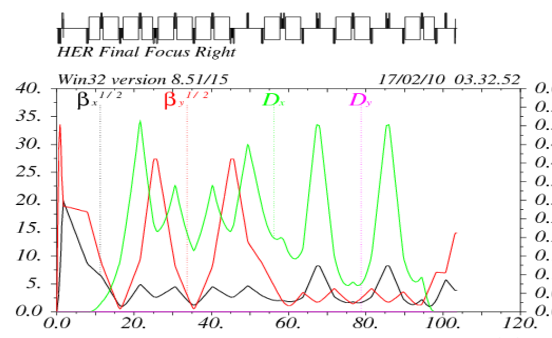

Figure 4: HER Final Focus optics on one side of IP.

Lattice functions in one half of the SuperB HER FF are shown in Fig. 4, where the IP with β_x/β_y = 26/0.27 mm is on the left. Several modifications were made to the NLC type system in order to adapt it to a ring operation:

- FF dipoles have the same polarity. This allows one to efficiently achieve the required bending angle between the IP and the Spin Rotator (SR) section.
- Dipole positions, lengths and strengths are optimized for a low emittance, high dispersion at sextupoles in the Chromatic Correction Section (CCS) and optimal geometric layout with 66 mrad IP crossing angle. Dipoles in the Y-CCS sections are weaker on one side of IP and stronger on the other side to provide the ±33 mrad asymmetry relative to the IP.
- Two sextupoles inserted in phase with the IP, at beam waist locations upstream the CCS, greatly increase the FF chromatic bandwidth.
- Crab Waist sextupoles are added at each end of the FF to preserve dynamic aperture of the system.

SPIN ROTATOR SECTION

Several schemes have been studied in order to provide a longitudinal polarization at the IP. They imply physical and optical constraints, necessary for proper spin rotation, which do reduce the FF flexibility and performance.

The schemes that do not use solenoids require vertical bumps. The latter cause significant degradation of the machine design parameters, in particular the vertical IP beam size. Therefore, such schemes were rejected, and a solution using solenoid Spin Rotator sections is adopted.

The chosen SR scheme includes a solenoid section at each end of the FF, where it is matched and locally decoupled, and where the net bending angle to the IP has the correct value for a proper spin rotation. Further studies showed that the solenoid SR in the HER (6.7 GeV) yields much more degradation to the machine performance than the one in the LER (4.18 GeV). This includes the impact on FF tuning ability, ring emittance, dynamic aperture, energy acceptance, and circumference. For these reasons, the SR sections are included in the LER. Their lattice functions are shown in Fig. 5.

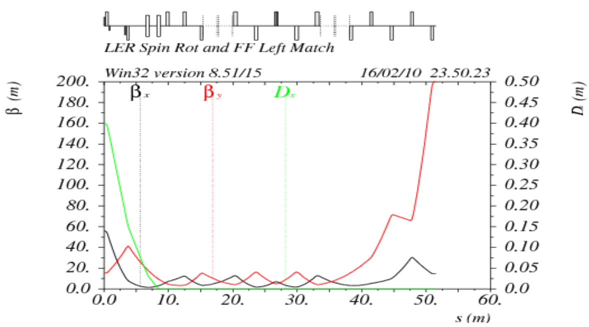

Figure 5: Lattice functions in the LER SR section.

LONG STRAIGHT SECTION

The long straight section connects the left and right Arcs on the opposite side of the FF. It will contain the RF cavities, tune trombones and other utilities. The straight has a FODO lattice, where the cell length is adjusted to fit two PEP-II RF cavities per half-cell. The injection sections are strategically moved out of the straight into the adjacent Arcs to provide maximum available space for other needs. The baseline RF scheme includes 14 HER and 8 LER cavities, however many more can be added later since >50 m of free space is available.

INJECTION SECTION

Beam injection will be performed in the horizontal plane in the dedicated Arc cells adjacent to the long straight section. The injection sections are created by proper lengthening and adjustment of one long Arc cell in each ring. They are located on the left and right sides of the long straight in the HER and LER respectively. Lattice functions in the HER injection section are shown in Fig. 6, and the LER section has a very similar design.

The injection septum is at the cell center, where β_x is large, and the injection kickers are at each cell end separated by 540° horizontal phase advance for a closed bump. The R_{12} term between the kickers and septum is maximized in order to reduce the necessary kick strength.

The HER injection section also provides the ring "parasitic" crossing point with ≈126 mrad angle as shown in Fig. 1. This is achieved by extending the HER injection section into crossing the LER straight section in such a way that the magnet interference is minimal and the resultant ring separation is ≈2.1 m in the long straight.

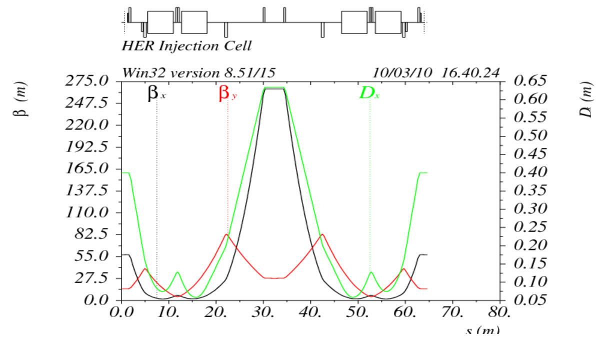

Figure 6: Lattice functions in the HER injection section.

COMPLETE RING LATTICE

The complete HER lattice functions are shown in Fig. 7, and the LER lattice is very similar except the Spin Rotator sections and the injection section on the other side of the long straight. The short ≈1258 m rings fit to the INFN-LNF site at Frascati. The HER and LER x/y betatron tunes are set to 40.575/17.595 and 42.575/18.595, respectively. The LER tune is higher due to the SR insertion. The HER/LER horizontal emittance at zero current is 1.97/1.82 nm·rad. The chromatic correction provides ±1% energy bandwidth. A complete list of SuperB parameters can be found here [6].

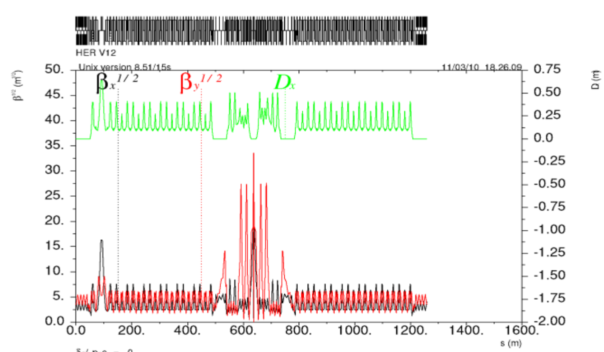

Figure 7: Lattice functions in HER, where IP is at center.

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