LOW EMITTANCE LATTICE AND FINAL FOCUS DESIGN FOR A SuperB PROJECT

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Abstract

Very low emittances and small beta functions at the interaction point(IP) are needed to achieve the design luminosity of 10^{36} cm^{-2} s^{-1} for a SuperB project. Two rings of 4 and 7 GeV have been designed with the same emittances and damping times. A new Final Focus section has also been designed to strongly squeeze the colliding beams both in the horizontal and the vertical plane at IP, while providing local correction of the large chromaticity and exploiting the large crossing angle and *crab waist* concepts. Lattice features and chromaticity correction schemes will be discussed here. Dynamic apertures, with damping wigglers similar to those of ILC, will also be presented.

INTRODUCTION

Recently, an alternative scheme to achieve an extremely higher luminosity was proposed for the SuperB project [1]. The SuperB project is a next generation B-Factory for pursuing 10^{36} cm^{-2}s^{-1} luminosity, which is the subsequent collider of PEP-II and KEKB[2]. The strategy is to have an ultra-low emittance beams and ultra-low beta functions at the IP with a large Piwinski angle. The bene t of this scheme is that the overlap region of colliding beams becomes $\sigma_x/2\phi_x$, while keeping the bunch length relatively long. Consequently, the vertical beta function at IP can be squeezed up to a level of 100 μm in principle, and together with the *crab waist* scheme [3], the luminosity can be much improved with respect to a conventional colliding scheme.

LATTICE DESIGN

The High Energy Ring (HER) has 6 arcs and 6 straight sections. Each arc has 12 cells and 250 m long approximately, which connects each straight section. The Final Focus (FF), including the IP, is placed in a straight section, while a magnetic chicane to transport beams across the other ring is placed in the opposite straight section of IP. The wiggler magnets, which control emittances and damping times, and the RF cavities are placed in the other four straight sections. The geometry of the Low Energy Ring (LER) is same as HER. The beam energy of HER is 7 GeV and the circumference is 2.28 km. The horizontal emittance is 0.8 nm. The small emittance is achieved by using two wiggler sections in HER (four in LER) and the arc cells. Each wiggler section is 40 m long approximately with a 0.83 T eld and 40 cm period length. The LER lattice is similar to the HER lattice, while the beam energy of LER is 4 GeV. The lattice parameters are shown in Table 1. Figure 1 shows the beta functions and dispersion in the HER.

Table 1: Lattice parameters

	LER	HER
Energy (GeV)	4	7
Circumference (m)	2275	
Emittance (nm)	0.8	
Horizontal beta at IP (mm)	20	
Vertical beta at IP (mm)	0.2	
Bunch length (mm)	6	
Transverse damping time (ms)	25	
Energy spread	1×10^{-3}	
Momentum compaction	1.8×10^{-4}	3×10^{-4}
Synchrotron tune	-0.011	-0.02
Total RF voltage (MV)	6	18

The arc lattice utilizes a kind of theoretical minimum emittance(TME) lattice, which consists of two bending magnets and three quadrupole families(QF, QFB and QD). The arc cell is 23 m long and has a betatron phase advance of π in the horizontal plane and 0.4π in the vertical plane. The intrinsic emittance of the arc cells is 1.46 nm. Chromaticity in the arcs is corrected with three sextupole families (SD1, SD2 and SF). Each sextupole magnet is placed in the immediate vicinity of each quadrupole magnet, where is a large β function to ef ciently correct the chromaticity. The optical functions in the HER arc cell are shown in Fig. 2.

The FF is designed to realize very small β-functions at IP, small geometric aberrations with non-interleaved sextupole pairs, and corrections of the large chromaticity generated in the Interaction Region (IR). The nominal values for the β-functions at IP are 20 mm in the horizontal plane and 200 μm in the vertical plane, with a distance of 30 cm between IP and the rst quadrupole magnet in the FF doublet. Since SuperB is a double-ring collider, the beams in HER and LER collide at IP and are separated with the horizontal crossing angle of 34 mrad. In the FF the same bending magnets as in the arc section are used to make dispersions in the region for chromaticity corrections. All bending magnets have the same sign to reduce the arc length and make the geometry simple. These bending magnets and matching quadrupole magnets make the dispersion zero at IP and localized within IR. The layout of FF is geometrically symmetric. Half of the FF section

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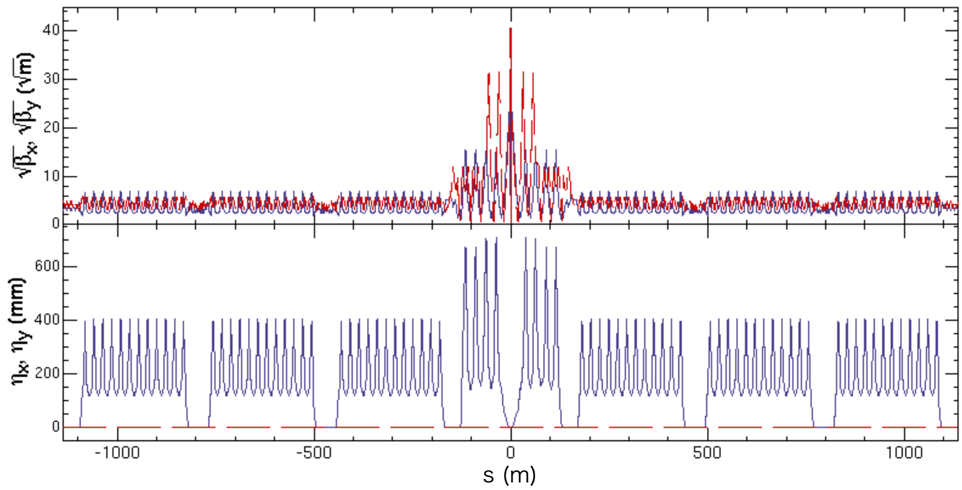

Figure 1: Optical functions, β-functions (upper) and dispersions (lower) in the HER. Solid and dashed lines show those in the horizontal and the vertical plane, respectively.

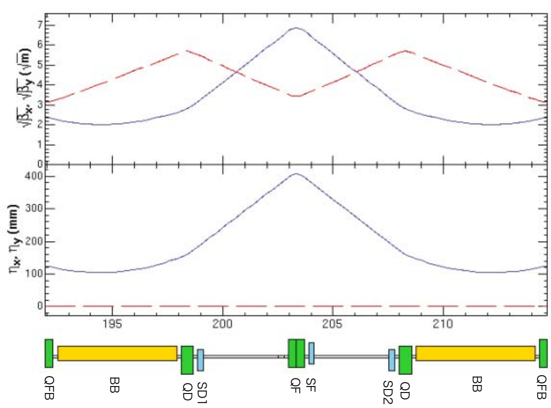

Figure 2: Optical functions, β functions(upper) and dispersions(lower) for the HER arc cell. Solid and dashed lines show those in the horizontal and the vertical plane, respectively.

is shown in Fig. 3. In order to make β-functions at IP very small, a large chromaticity is generated and should be corrected locally as much as possible. A local chromaticity correction is adopted in the FF design. The identical sextupole magnets are connected with a -I' transformation matrix:

$$\begin{pmatrix} -1 & 0 & 0 & 0 \\ m_{21} & -1 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ 0 & 0 & m_{43} & -1 \end{pmatrix} \tag{1}$$

in the local chromaticity correction. The sextupole pairs reduce nonlinearities for each other, while correcting the chromaticity. Therefore, the dynamic aperture for the off-momentum particles can be increased. Two pairs of sextupole magnets for the local chromaticity correction are placed both in the horizontal plane (SFX0 and SFX4) and the vertical plane (SDY0 and SDY4). Additional sextupole magnets, which are IP phase sextupoles (SDM2 and SFM7), are introduced to improve the behavior of off-momentum particles. The location of the IP phase sextupoles is in a minimum β-function for on-momentum particles, while in a maximum β-function spot for off-momentum particles. In SuperB, the *crab waist* collision scheme is adopted to increase the luminosity. In this scheme, the waist position, which is the minimum position of the β-function, is adjusted by a kick from the sextupole magnets to suppress the hourglass effect in the vertical plane. Thus, the particles collide with the other beam at their waist point, and beam-beam interaction and betatron coupling resonances induced by the crossing angle are suppressed. The sextupole magnets (MCRAB, one of two in Fig. 3) for the *crab waist* are located in both sides of the matching section between the FF section and the arc sec-

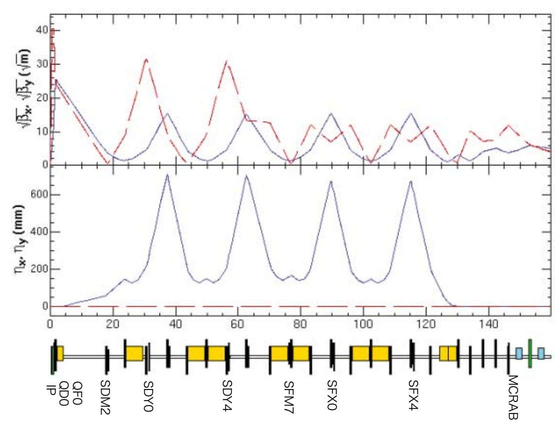

Figure 3: Optical functions, β-functions(upper) and dispersions(lower) for the FF section. Solid and dashed lines show those in the horizontal and the vertical plane, respectively.

tion. The β-functions at the *crab waist* sextupole are 14 m in the horizontal plane and 140 m in the vertical plane, respectively. The betatron phase advances between the sextupole magnet and IP are 6π in the horizontal plane and 5.5π in the vertical plane. The K_2 value of the sextupoles is taken to be 20(or -20) m^{-2}, which is 50 %(75 % for β_y^*=0.3 mm) of the nominal value determined by

$$K_2 = \frac{1}{\tan 2\phi_x \cdot \beta_{y,sext}\, \beta_y^*} \sqrt{\frac{\beta_x^*}{\beta_{x,sext}}}, \qquad (2)$$

where ϕ_x is the half crossing angle.

CHROMATICITY CORRECTION

The betatron tunes for HER have been chosen to be 48.57 in the horizontal plane and 23.60 in the vertical plane. The linear chromaticity is adjusted to be close to zero using three families of the sextupoles in the arc section and six families in FF. Figure 4 shows deviations of the betatron tunes and betatron functions at IP for the off-momentum particles. The betatron tunes and β-functions at IP are corrected within 5 % for the bandwidth of ± 1 % momentum deviation. There is a small discrepancy, especially the vertical β-function at IP between sextupoles when the *crab waist* are turned on and off, due to the dispersion for large off-momentum particles generated at the *crab waist* sextupoles. However, the difference between them is negligible concerned with the chromaticity correction.

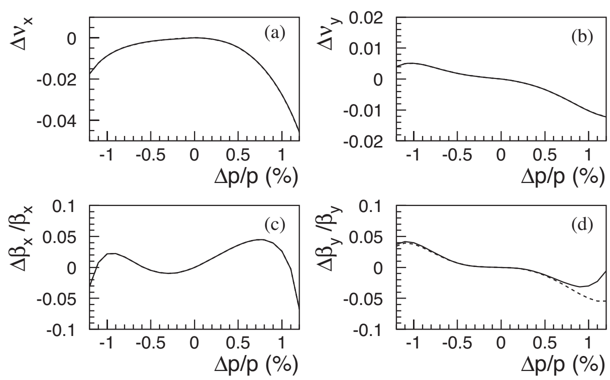

Figure 4: Chromatic effects for the HER ring. Betatron tunes(upper) and β functions(lower) as a function of momentum deviation in the horizontal and the vertical plane. The solid and dashed lines show the case in which the sextupole magnets for the *crab waist* on and off, respectively.

DYNAMIC APERTURE

A dynamic aperture is de ned by requiring stability in 1000 turns with a synchrotron oscillation and without radiation damping, which gives the exactly same result in one transverse damping time with radiation damping. The dynamic aperture is estimated by numerical tracking simulations using SAD [4], which is an integrated code for optics design, particle tracking, and so on. Figure 5 shows the dynamic aperture from the tracking simulations for HER, assuming the ideal lattice. The $2J_x$ and $2J_y$ are Courant-Snyder invariants in the horizontal plane and the vertical plane. The initial vertical amplitude, $2J_y$, is xed to be zero when the horizontal aperture is evaluated, and vice versa.

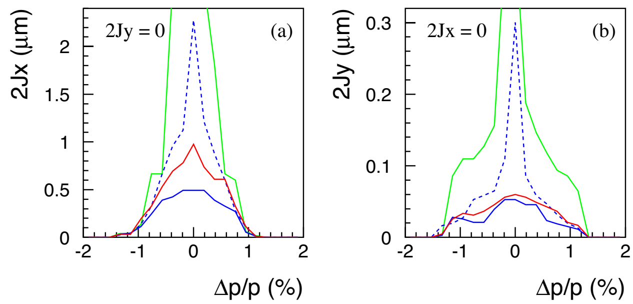

Figure 5: Horizontal aperture (a) and vertical aperture (b) as a function of momentum deviation. Green and blue solid lines show the sextupole magnets for the *crab waist* are turned off and on, respectively. Further octupole corrections are indicated by red solid lines. Blue dashed lines show the case without fringe effects for the *crab waist* on, while octupole corrections off.

CONCLUSION

The lattice design for the very low emittance and the FF of the SuperB have been presented. The large chromaticity generated at IR is corrected by the local chromaticity sextupole correction. The dynamic aperture is signi cantly reduced when the sextupoles for the *crab waist* turned on. If the nonlinear fringe eld (Maxwellian fringe) of the all magnets is turned off, the dynamic aperture is restored by 60 %. Strong quadrupoles in FF, especially, the fringe effect of the FF quadrupole magnets affects the dynamic aperture. The octupole magnets in the immediate vicinity of the FF quadrupoles (QD0 and QF0) improve the dynamic aperture in the horizontal plane by a factor 2 of the case without the octupole optimization. A new version, shorter version of this lattice is being studied at present, with modi cations of the phase advance/cell. From preliminary results it seems that increasing the horizontal phase advance/cell in the regular cells will allow to have a shorter, more e xible ring optics, without using wigglers.

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