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POLARIZED BEAMS IN THE SUPERB HIGH ENERGY RING *

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Abstract

The proposed Super-B factory will provide longitudinal polarized electrons to the experiment. Vertically polarized electrons will be injected into the High Energy Ring (HER); the vertical spin orientation will be locally rotated into the longitudinal direction before the interaction point and back afterwards to avoid spin depolarization. The spin rotators can be designed using compensated solenoids, as proposed by Zholents and Litvinenko, to rotate the spin into the horizontal plane, followed by dipoles for horizontal spin rotation into the longitudinal direction. Such spin rotators have been matched into the existing lattice and combined with the crab-waist IR. Several ways of achieving this are explored, that differ in the degree of spin matching achieved and the overall geometry of the interaction region. The spin rotation can also be achieved by a series of dipole magnets only, which present a different optical matching problem. We will compare the different scenarios leading up to the adopted solution.

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The proposed Super-B factory will provide longitudinal polarized electrons to the experiment. Vertically polarized electrons will be injected into the High Energy Ring (HER); the vertical spin orientation will be locally rotated into the longitudinal direction before the interaction point and back afterwards to avoid spin depolarization. The spin rotators can be designed using compensated solenoids, as proposed by Zholents and Litvinenko, to rotate the spin into the horizontal plane, followed by dipoles for horizontal spin rotation into the longitudinal direction. Such spin rotators have been matched into the existing lattice and combined with the crab-waist IR. Several ways of achieving this are explored, that differ in the degree of spin matching achieved and the overall geometry of the interaction region. The spin rotation can also be achieved by a series of dipole magnets only, which present a different optical matching problem. We will compare the different scenarios leading up to the adopted solution.

INTRODUCTION

Polarized colliding beams have been successfully used in SLC and HERA colliders. The challenge for the proposed Super-B facility is that it uses the so called crab-waist scheme which has recently been successfully tested at the DAPHNE collider at LFN. It is essential for this scheme,

Table 1: Super-B HER Parameter March 2009 Option

Param.	Unit	
E	GeV	7
L	cm^{-2} s^{-2}	1×10^{36}
N_{bunch}		2400
$\beta_x^\star$	mm	20
$\beta_y^\star$	mm	0.37
ϵ_x	nm	1.6
ϵ_y	pm	4
$\sigma_x^\star$	μm	5.7
$\sigma_y^\star$	nm	38
$\sigma_z^\star$	mm	5

that the chromatic errors between the interaction point (IP) and the location of the crab waist sextupoles, mainly generated by the final focus (FF) doublet, are close to completely corrected. With the small beam sizes at the IP (see Table 1) the FF is very sensitive to any perturbation introduced. To successfully introducing a spin rotator in this area the chromatic characteristic of the original design necessary for the crab waist scheme especially the band width and dynamic aperture, has to be maintained.

FINAL FOCUS

Original Final Focus

The lattice of the HER was originally designed without the option of colliding polarized beams. To obtain the best results for with respect to the polarization the spin rotators (SR) are placed as close as possible to the IP. Fig. 1 shows the right hand side of the original FF. This design is

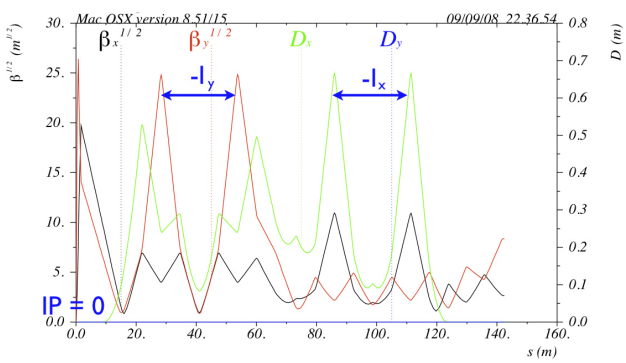

Figure 1: Original half FF optics.The IP is located at 0.0 meter followed by the vertical $(-I_y)$ and horizontal $(-I_x)$ chromaticity correction section. The crab waist sextupoles are located on the far right hand side.

very compact and beside the standard correction section for the chromatic errors generated in the FF doublet a second group of sextupoles have been introduced as shown in fig. 2 with the names SDM2, SFM7 and SFM9. These sextupoles have a phase shift compared to the $-I$ of 90 degree. The function of the first two is to correct the off energy errors at the $-I$ pair so that the chromatic correction of the FF doublet is also working for off energy particles. Geometric errors generated in these sextupoles are compensated by the third sextupole. All of these sextupoles are in phase with close to 2Π phase advance. Fig. 2 also shows the phase advances from the IP to the various elements. Any change

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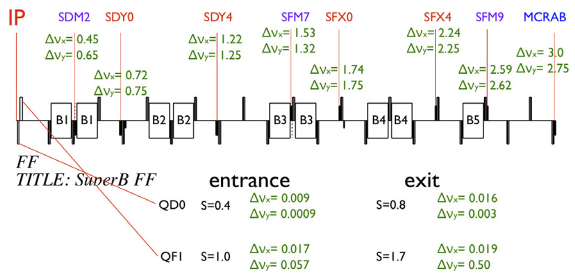

Figure 2: Original half FF magnet layout. SDY0/4 compose the vertical and SFX0/4 the horizontal $-I$ sections. SDM2, SFM7 and SFM9 are the off-phase sextupoles.

in the fractional phase advance in the order 1 degree has an impact on the nonlinear correction. The error of the chromatic β-functions at the IP and the locations of the crab sextupoles are very small which is a necessary condition.

Spin Rotator

Fig. 3 shows the principle layout of a standard spin rotator using solenoids and dipoles. Vertically polarized electrons are injected into the ring and preserved by the horizontal bending magnets. To collide longitudinally polarized electrons one has to flip the orientation from the vertical into the longitudinally direction at the IP and back after the IP to preserve polarization. There are several ways this can be done but with the conditions for the HER and other considerations the adopted scheme was chosen as the optimal.

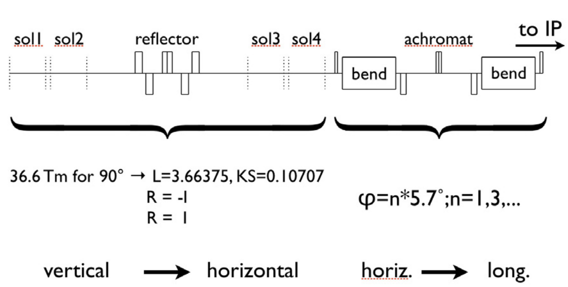

Figure 3: Standard arrangement of an spin rotator using solenoids and horizontal dipoles.

mal. The orientation is first flipped from the vertical into the horizontal plan with solenoids. To cancel the coupling of the solenoids two pairs are use with a specific transformation matrix between them ($R_x = 1 \text{and} R_y = -1$ or vice versa). The orientation is then flipped into the longitudinal direction using a pair of dipoles arranged as an achromat. After the collision the particles run through the same setup on the opposite side in reverse direction. The dipole can bend in principle bend in the same direction on both sides but to preserve polarization for off energy particles it is advantageous to bend in the opposite direction. This creates a s-bend geometry in the FF.

Super-B Final Focus with Spin Rotator

There is no straight forward location for the integration of the SR. Several options were investigated. The location least compromising for all the necessary condition is the area between the chromatic correction sections. One necessary condition for the SR is that the dispersion in the solenoid section equals zero which is not the case in this location. Additionally there is the off phase sextupole for the horizontal $-I$ pair located at this point which needs dispersion to be non-zero. Also the SR demands that the total bending angle between the IP and the solenoid section is an uneven multiple of an energy dependent value. In addition to save space the vertical bending section was integrated into the vertical $-I$. Unfortunately the bending angle was about twice as large as the angle demanded for the SR. Increasing this angle changed the horizontal emittance by a factor of two. Decreasing it the angle necessitated an increase of the $-I$ sextupole strength which reduced the dynamic aperture dramatically. As a solution an additional half of an $-I$ was added to the vertical correction section which provided the demanded bending angle

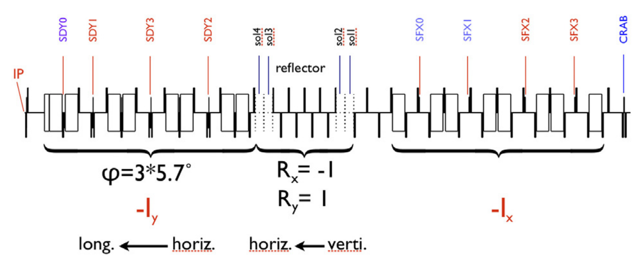

Figure 4: Original half FF magnet layout. Noticeable are the changes in the vertical $-I$ section which is now a triple and the additional $-I$ pair in the horizontal correction section.

with no increase of the horizontal emittance. For the off energy sextupole a complete $-I$ pair was introduced. The new FF magnet layout with the SR integrated is shown in fig. 4. Fig. 5 depicts the TWISS functions of the new FF design.

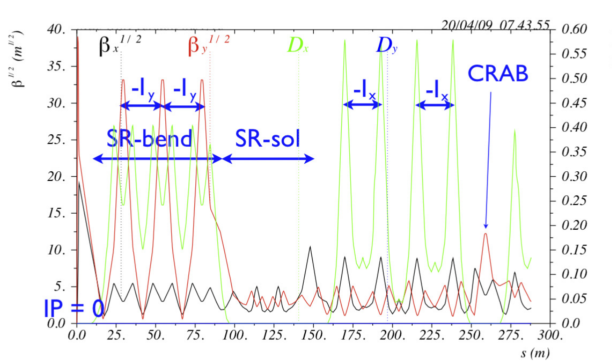

Figure 5: TWISS functions of the new right half of the FF.

CHROMATIC CHARACTERISTICS

The integration of the SR necessitated a complete redesign of the FF. The first attempt was unsuccessful because the used reflector in the solenoid section introduced a too large chromatic error. Only after replacing it with a version utilizing more and therefore weaker quadrupoles reduced its chromatic error to an acceptable level. This had the disadvantage of increasing the overall ring length. We used several figures of merit to characterize the chromatic behavior of the new FF. On is the so-called W-function as calculated by MAD. As mentioned earlier the crab waist

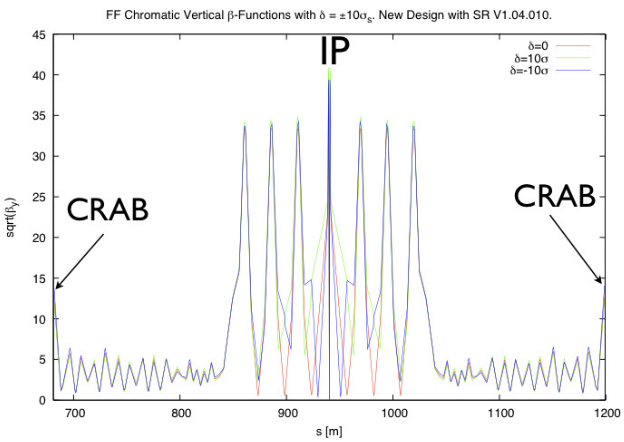

Figure 6: On (red curve) and off energy (green $+10\delta_E$ blue $-10\delta_E$) β-functions.

scheme demands a small difference of the chromatic β-functions in the location of the IP and the crab sextupoles. Plot 6 depicts the on (red curve) and off energy (green $+10\delta_E$ blue $-10\delta_E$) β-functions. The achieved error is within tolerable boundaries but improvement is still possible. Further the bandwidth is calculated. This is the IP β-function as a function of the energy offset. At $10\delta_E$ the change of the variation should be smaller than 10% with $\delta_E = 6.7 \times 10^{-4}$. Fig. reff10 plots both horizontal (black curve) and vertical (red curve) β-function. Latter is very flat while latter shows large higher order components.

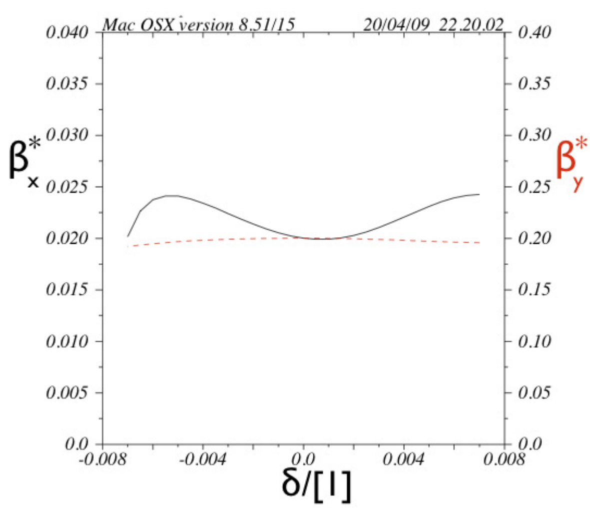

Figure 7: Bandwidth plot. The black curve depicts the horizontal, the red the vertical IP β-function as a function of the energy. 7×10^{-3} corresponds to ten times the energy spread of the beam.

TRACKING RESULTS

For preliminary check of the dynamic aperture the lie tracking method of MAD8 was used with the following conditions:

- Synchrotron radiation OFF
- RF OFF
- Horiz. emittance $\epsilon_x = 1.6 \times 10^{-09} nm$
- Vert. emit. fully coupled $\epsilon_y = \epsilon_x/2 = 0.8 \times 10^{-09} nm$
- Initial condition offset calculated from β-functions at launch point

The results for the dynamic aperture as a function of the different initial conditions are shown in Table 2. The results clearly show that this is a workable solution but also that improvement is necessary.

Table 2: Maximum Dynamic Aperture Results from MAD Tracking with no Errors

plane	δ**E** [%]	max dyn. apert. [$\sigma_{x,y}$]
horz.	0	$50\sigma_x$
horz.	$10\sigma_E$	$20\sigma_x$
horz.	$10\sigma_E$	$20\sigma_x$
vert.	0	$30\sigma_y$
vert.	$10\sigma_E$	$6\sigma_y$
vert.	$10\sigma_E$	$12\sigma_y$

CONCLUSIONS

We have established a solution for the HER of the Super-B project, which provides longitudinal polarized electrons for collisions. The SR is located in between the vertical and horizontal chromatic correction section of the FF. The impact on the chromatic characteristic such as bandwidth and dynamic aperture are tolerable but improvement is still necessary.