COMPENSATION OF DETECTOR SOLENOID IN SUPER-B*

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Abstract

The SUPER-B detector solenoid has a strong 1.5 T field in the Interaction Region (IR) area, and its tails extend over the range of several meters. The main effect of the solenoid field is coupling of the horizontal and vertical betatron motion which must be corrected in order to preserve the small design beam size at the Interaction Point. The additional effects are orbit and dispersion caused by the angle between the solenoid and beam trajectories. The proposed correction system provides local compensation of the solenoid effects independently for each side of the IR. It includes bucking solenoids to remove the solenoid field tails and a set of skew quadrupoles, dipole correctors and anti-solenoids to cancel linear perturbations to the optics. Details of the correction system are presented.

INTRODUCTION

The Interaction Region (IR) of the proposed SUPER-B e^+e^- collider [1] includes a strong 1.5 T detector solenoid field, where the solenoid tails extend over several meters around the Interaction Point (IP). The solenoid creates coupling of the horizontal and vertical betatron motion which must be corrected in order to preserve the design ultra small beam size at the IP. The additional complications are that the solenoid is not parallel to either of the two beams, and it overlaps the innermost IR permanent quadrupoles. These lead to orbit and dispersion perturbations and additional coupling effects. The proposed correction system will provide local compensation of the solenoid linear effects independently for each side of the IR.

SOLENOID FIELD MODEL

Solenoid compensation studies for PEP-II [2] and ILC [3] indicate that the solenoid overlap with the final quadrupoles can significantly increase the coupling effect leading to larger IP beam size. Therefore, it is desirable to minimize the extent of the solenoid field tails and try to avoid superposition of the solenoid and quadrupole field. Previous SUPER-B study [4] proposed using so-called bucking solenoids to create opposite to detector solenoid field in the region of the IR superconducting (SC) quadrupoles and effectively cancel the solenoid tails. Fig. 1 shows the magnet layout near the IP with the detector solenoid and bucking solenoids.

In this study, we use a simplified hard-edge solenoid model where the solenoid field is constant (1.5 T) in the ±55 cm region around IP (between the left and right hand side SC quadrupoles) and the field is canceled outside of this region using bucking solenoids. This effective detector solenoid and its field profile are shown in Fig. 2. The solenoid axis is at ±33 mrad horizontal angle relative to the colliding e^+ and e^- beam trajectories. The solenoid field overlaps the IR innermost permanent quadrupoles QD0P. The resultant field superposition is modeled in MAD [5] by replacing the thick QD0P quadrupoles with thin lens quadrupoles separated by thick solenoid slices. This model can also be extended to a non-constant field profile by applying different field values in the solenoid slices. Some high-order perturbations may be missing due to limitations in the MAD solenoid model.

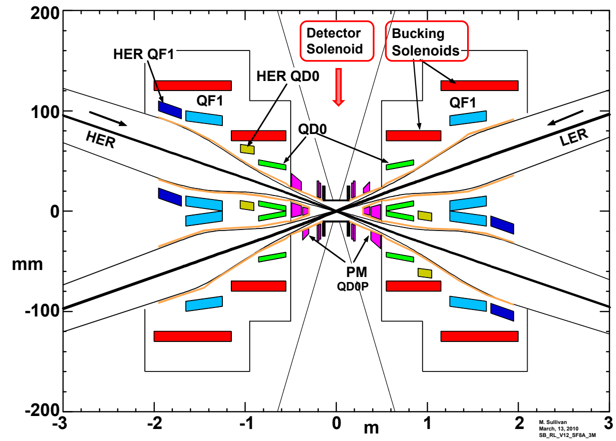

Figure 1: IR layout with detector and bucking solenoids.

OPTICS PERTURBATIONS

The SUPER-B detector solenoid creates the following linear effects on the 6.69 GeV positron and 4.18 GeV electron beams:

- Coupling of X and Y betatron motion which in absence of other magnets creates a beam rotation around S-axis by an angle $B_sL/(2B\rho)$, where B_s and L are

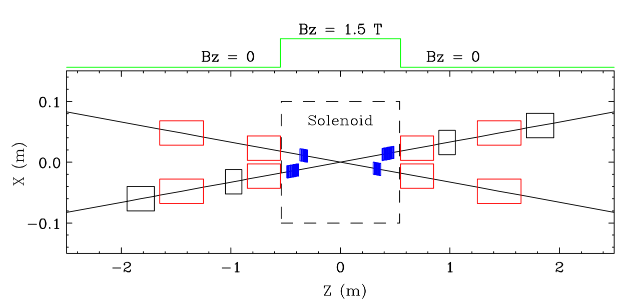

Figure 2: Effective hard-edge detector solenoid near IP.

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solenoid field and length. For each half of the above solenoid the corresponding rotation angle is 29.6 mrad for e^- and 18.5 mrad for e^+ beam.

- Vertical orbit due to the solenoid angle relative to the beam trajectories. This is caused by the solenoid horizontal field projection on the beam axis. Note that the solenoid end fields have an opposite horizontal field providing partial compensation of this effect.
- Horizontal orbit from the vertical orbit and coupling.
- Vertical and horizontal dispersion due to the Y and X orbit bending.
- Perturbation of β functions due to solenoid weak focusing in both planes.

COMPENSATION SYSTEM

Ideally, the solenoid correction system should be as local as possible in order to prevent the effects of errors on coupling correction from other magnets in the Final Focus (FF). The most efficient correction would consist of an anti-solenoid attached to each side of the detector solenoid without overlap with other magnets. In this case, the coupling would be canceled for all particle energies. In the SUPER-B IR, however, the detector solenoid already overlaps the permanent quadrupoles, and sufficient free space exists only after the SC quadrupoles. For these reasons, most of the solenoid correctors have to be installed outside of the SC quadrupoles, i.e. in the FF chromatic section and beyond. To cancel the solenoid effects at the IP and in the arcs, the correction must be local and independent on each side of the IR. In total, the system must include correctors for the solenoid coupling, X and Y orbit and dispersion, and β functions.

The coupling correction requires skew quadrupoles and/or solenoid correctors. The bucking solenoids have been already included to remove the solenoid field tails. Additional anti-solenoid equivalent to half of the detector solenoid with opposite strength is inserted on beam axis after the SC quadrupoles on each side of IP. It would compensate the beam rotation if there were no magnets between the IP and anti-solenoid. However, the permanent and SC quadrupoles can create a significant coupling perturbation. This is because the rotated beam will be effectively at an angle relative to the quadrupole $X - Y$ frame, thus resulting in skew quadrupole effects. This perturbation can be avoided by rotating the quadrupole frame by the rotation angle of the incoming beam as schematically shown in Fig. 3. The required quadrupole tilt angles are proportional to the distance to the IP, and are different for e^- and e^+ beams due to energy difference. Technically, the rotation of closely spaced e^- and e^+ SC quadrupoles would be complicated. However, it is possible to design the SC coil with skew quadrupole component and strength equivalent to quadrupole rotation. The latter is assumed for this correction system.

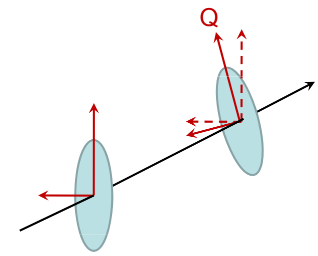

Figure 3: Quadrupole rotation to align with beam rotation.

Still some small residual coupling will be created by the permanent quadrupoles because they cannot be continuously rotated along the length as the beam frame. Compensation of this residual coupling requires four relatively weak skew quadrupoles at non-dispersive locations and optimal phase advance in each half-IR. Two additional skew quadrupoles located in dispersive region of the FF chromatic section in each half-IR are used to cancel the vertical dispersion and slope at the IP. Locations of the six Low Energy Ring (LER) skew quadrupoles in a half-IR are shown in Fig. 4. Note that the first skew quadrupole is placed next to the SC quadrupoles for efficient correction of their coupling. The High Energy Ring (HER) has almost identical system.

The correction of solenoid orbit is rather straightforward and requires two horizontal and two vertical dipole correctors on either side of IP. For minimal perturbations these correctors are placed in the drift after the SC quadrupoles. The resultant orbit after correction in LER is shown in Fig. 5. The corrector positions within $\pm$7.5 m of IP are shown in Fig. 6, which include V1,V2 and H1,H2 dipole correctors, QS1 skew quadrupole and anti-solenoid. The other skew quadrupoles are outside of this range.

Finally, the correction of IR β functions and horizontal dispersion is done using strength adjustment in the IR normal quadrupoles. This system compensates locally and independently in each half-IR the linear solenoid effects at the IP and outside of the IR. Note that it is designed to cancel the on-energy coupling, however the off-energy particles will see slightly different optics for which some residual chromatic coupling will be present. The latter may require further study.

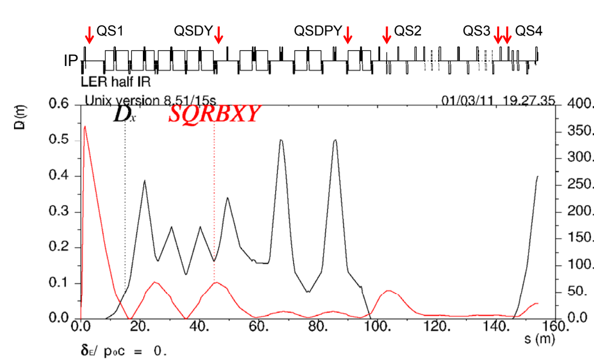

Figure 4: LER skew quadrupoles in half-IR. Plotted functions are dispersion and $\sqrt{\beta_x \beta_y}$.

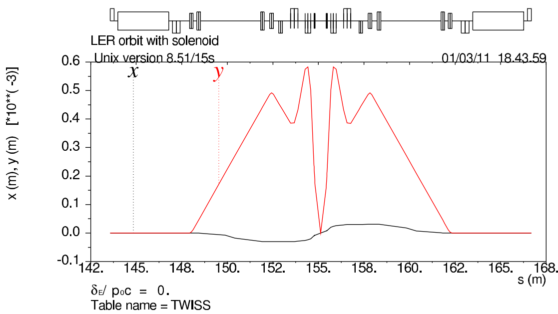

Figure 5: Corrected orbit in the LER IR.

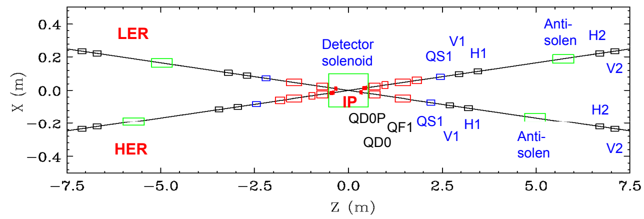

Figure 6: Solenoid correctors within ± 7.5 m of IP.

An example of this coupling correction is shown in Fig. 7. The latter show tilt angles for two normal mode beam ellipses projected on X-Y plane as calculated by EIGEN routine in MAD [5] for the LER. This clearly shows that the coupling is localized within the IR.

If Panofsky quadrupoles are used instead of SC quadrupoles, it may not be possible to create the skew component from the coil. In this case, the whole LER/HER shared quadrupole assembly may be rotated. This will not produce the optimal rotation for both the LER and HER quadrupoles, therefore stronger coupling correctors will be needed. In addition, such rotation will result in vertical quadrupole offsets which effect can be corrected by the solenoid dipole correctors.

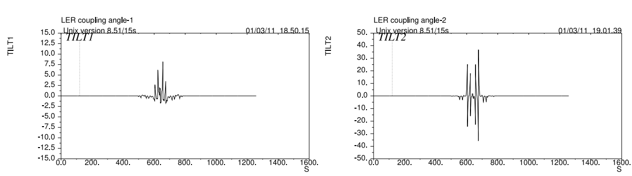

Figure 7: LER beam tilt angle (deg) for modes 1 and 2.

SOLENOID OFF

When the solenoid field is off, one wants to turn off all the solenoid correctors and have uncoupled lattice. However, in this correction system there are elements which may not be turned off. These are the skew components in the SC quadrupoles which are permanently included through adjustment of the SC coil design. Secondly, the rotation of the permanent quadrupoles near IP may or may not be adjustable.

When all the solenoid fields are turned off, the beam does not receive the rotation, therefore it is no longer aligned with the rotated permanent quadrupoles. As a result, the latter and the SC skew quadrupole components become the major sources of coupling. These are amplified by the high β functions in these quadrupoles. This coupling can be compensated by the included four skew quadrupoles at non-dispersive locations, however their strengths will be increased relative to the solenoid on case. The disadvantage is that the stronger skew quadrupoles make the system effectively less local because they are located relatively far from the IP as seen in Fig. 4.

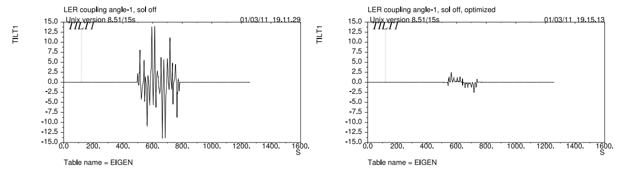

Figure 8: LER beam tilt angle (deg) for mode 1 with solenoid off. Left - original QD0P rotation, right - optimal QD0P rotation.

If the rotation of the IR permanent quadrupoles is adjustable, it can be optimized for a more local coupling correction where the QS3, QS4 quadrupoles are made weak. This, indeed, significantly reduces the amplitude of the coupling amplitude in the IR. Two cases are compared in Fig. 8: 1) with the original QD0P rotation angle from the solenoid set-up and 2) with optimized rotation angle. The latter option reduces the QS3, QS4 strengths to negligible level and produces much lower coupling amplitude.

Finally, there is no orbit and dispersion perturbation in the solenoid off case, hence the dipole correctors and the two skew quadrupoles at dispersive locations are not used.

SUMMARY

A correction system for the SUPER-B detector solenoid is designed based on a hard edge solenoid field model. It includes bucking solenoids, an anti-solenoid, rotated IR permanent quadrupoles, skew quadrupole component in the SC quadrupoles, and a full set of skew quadrupoles and orbit correctors for complete compensation of linear coupling, orbit, dispersion and β function perturbation in each half-IR. Most of the correctors are rather weak. The same system can be used to correct the coupling effect when the solenoid is off, but the SC quadrupole coupling components and QD0P rotation remain. The latter can be adjusted for most local correction. Further studies are needed to evaluate the effect of solenoid on FF bandwidth and dynamic aperture. The non-linear solenoid effects need to be studied as well.

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