SOLENOID COMPENSATION FOR THE SUPERB INTERACTION REGION*

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Abstract

We present an approach for compensating adverse effects of the detector solenoid in the Super*B* Interaction Region (IR). We place compensating solenoids around the IR quadrupole magnets to reduce the magnetic fields nearly to zero. This allows more operational headroom for superconducting IR magnets and avoids saturation of ferric IR magnets. We place stronger compensating solenoids between IR magnets to reverse the magnetic field direction. This allows adjusting the total integrated solenoid field to zero, which eliminates coordinate plane rotation and reduces vertical beam displacements in the IR.

INTRODUCTION

The Super*B* accelerator design [1, 2] uses high-current (~1-2 A), very low emittance (~2 nm-rad in x and ~5 pm-rad in y) beams with a crabbed waist crossing angle scheme (allowing β_y^* values of ~0.2 mm) to achieve a design luminosity of 1×10^{36} $cm^{-2}s^{-1}$, at least 50 times higher than current B-factories.

The baseline IR design incorporates permanent magnet (PM) and super-conducting (SC) quadrupoles to achieve these very small design β^* values [3]. Panofsky-style super-ferric quadrupole magnets have recently been added to the design [4].

The detector solenoid field is nominally orthogonal to these quadrupole magnetic field directions. But it could potentially add to magnetic fields in the SC winding turnaround regions, limiting SC quadrupole excitations. It would also drive a large flux through any super-ferric magnets, potentially reducing their maximum excitation. For both of these reasons, it is desired to cancel the detector solenoid field over the IR quadrupoles.

The detector solenoid also introduces x-y coupling of the beam, which must be removed in some way. This could be done with skew quadrupoles or with solenoids.

SOLENOID COMPENSATION

Concept

Both of these problems can be addressed by the use of compensation solenoids in the IR, coaxial with the detector solenoid. The concept is to provide "bucking" fields over the quadrupole locations, reducing the external B-field at the quadrupole locations nearly to zero.

Additionally, solenoid windings would over-compensate the B-field where quads are absent, so that the line integral of B_z goes to zero when taken from the interaction point (IP) out of the detector along the beam trajectory in either direction (Eq. 1). This will cancel coordinate plane rotation, nominally canceling x-y coupling. Applying this compensation as close to the IP as possible minimizes particle off-axis offsets and angles in the IR.

$$\int_{IP}^{\pm\infty} B_z dz = 0 \tag{1}$$

Implementation

Table 1 lists some of the parameters for the high-energy beam (HEB) and low-energy beam (LEB) used in this analysis. Fig. 1 presents a drawing of the baseline IR design from early 2009. The June 2009 baseline has a slightly different configuration of PM slices, and the current design adds super-ferric quadrupole magnets [4].

Table 1: Some Machine Parameters Important for the IR

Parameter	HEB	LEB
Energy (GeV)	7.0	4.0
Current (A)	2	2
β_x^* (mm)	20	35
β_y^* (mm)	0.37	0.21
Emittance x (nm-rad)	1.6	2.8
Emittance y (pm-rad)	4	7
Crossing angle (mrad)	60	

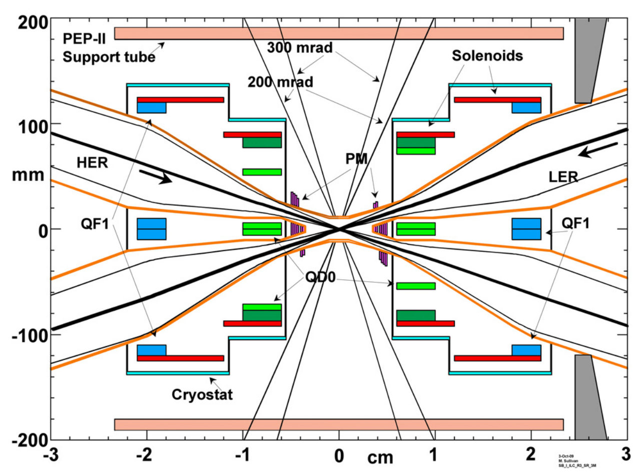

Figure 1: Baseline design of the Super*B* IR.

The baseline design of Fig. 1 includes compensation solenoids (red) to cancel the detector solenoid field at the quadrupole locations. But due to fringe fields, the solenoids as shown cannot do an adequate job of canceling the detector field both in the body and at the

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ends of the quadrupoles. Additional coils (or higher winding density) would be needed at the ends of these compensation solenoids. In addition, the baseline design cannot satisfy Eq. 1, so cannot remove x-y coupling.

An improved set of compensation solenoids for the baseline design is presented in Fig. 2. The solenoids of Fig. 1 have been shortened, additional small trim coils have been added at some solenoid ends, and large solenoids have been added between quadrupoles to over-compensate the detector solenoid and satisfy Eq. 1. Some of the coil excitations are fairly high, but are not unreasonable for realistic superconducting solenoid designs in the available space.

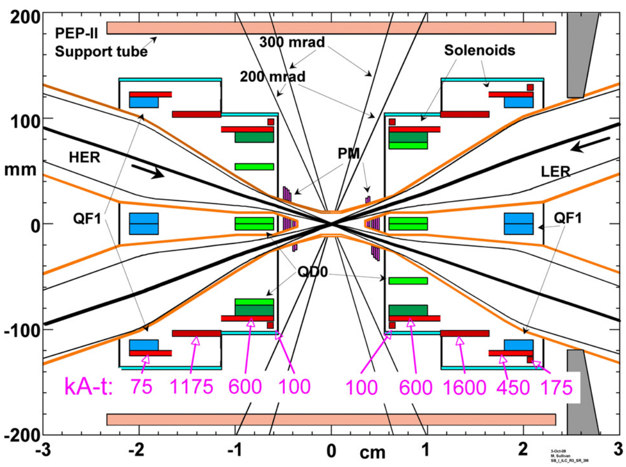

Figure 2: Compensation solenoids added to baseline IR design. Coil excitations are given in kA-turns.

The magnetic fields due to this compensation approach are shown in Fig. 3. The largest curve (red) shows B_z on axis. The smaller curves show the B_x along the beam trajectory in the detector solenoid coordinate frame (green) and in the beam coordinate frame (blue), which has a crossing angle relative to the detector solenoid frame.

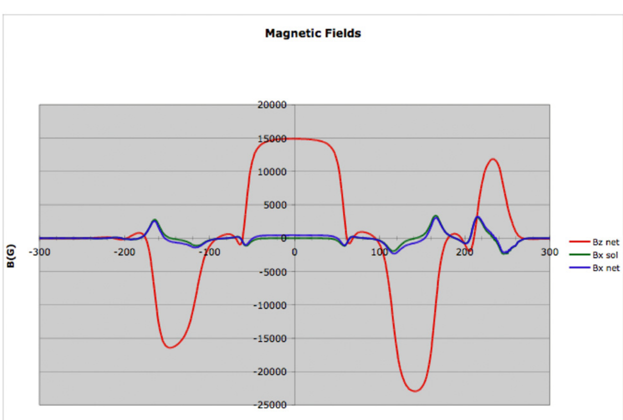

Figure 3: Magnetic fields in IR due to combination of detector solenoid and compensation solenoids.

Solenoid compensation has reduced B_z in the body of the quadrupoles to < 1.5 kG, less than 10% of the nominal detector field. The B_z near the quadrupole ends is not very smooth; this can be improved by a gradually varying the winding density of the trim coils that were added at the ends of the compensation solenoids.

Beam Offsets and Angles

The transverse B_x fields kick the beam in the y-direction. The resultant offsets and angles for the LEB are shown in Fig. 4. Offsets do not exceed 1 mm, which is acceptably small. The higher energy HEB will have proportionately smaller offsets and angles in the IR. By virtue of satisfying Eq. 1, the beams are forced to have no offset or angle where they cross, at the IP.

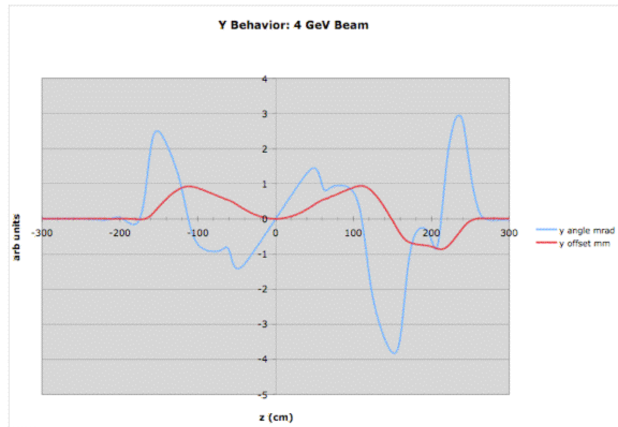

Figure 4: LEB offsets and angles in IR.

The offsets and angles shown in Fig. 4 do not include quadrupole kicks. The quadrupoles will introduce kicks, but these will be small and easily correctable. (The quadrupoles would not introduce kicks if they were offset and rolled slightly. But this would add complexity and asymmetry to the IR design, so is not planned.)

Detector Field Distortion

The implementation of compensation solenoids slightly distorts the detector field near the IP, and reduces its magnitude by about 200 G (Fig. 5). If necessary, additional trim solenoids could be added over the PM quads to reduce this perturbation.

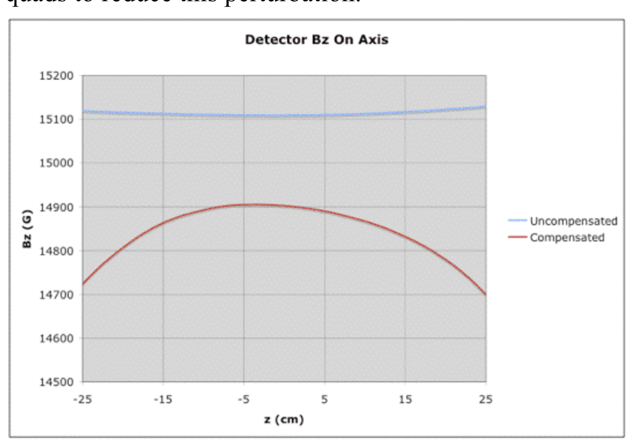

Figure 5: Effect of solenoid compensation on detector field near IP.

ADDITION OF PM CYLINDERS

We have also investigated the possibility of increasing B_z near the axis by the addition of PM material, in an attempt to help reject low-energy background particles. Cylindrical shells of 14 kOe NdFeB were modeled, each with an ID of 2.5 cm, and OD of 3.5 cm, and a length of 10 cm, centered 20 cm from the IP. Axially magnetized cylinders and the resultant field perturbations are shown in Figs. 6 and 7. Radially magnetized cylinders are shown in Figs. 8 and 9.

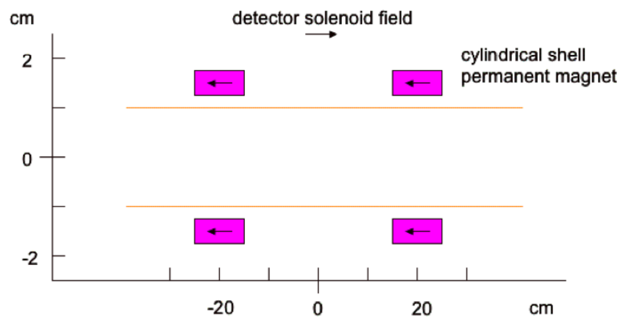

Figure 6: Axially magnetized PM cylinders near IP.

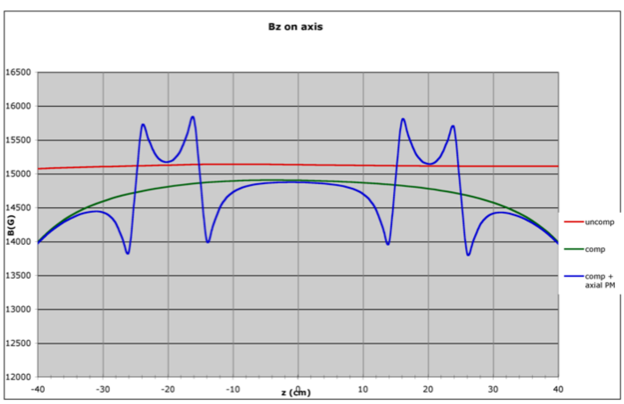

Figure 7: Magnetic field distortion produced by axially magnetized PM cylinders near IP.

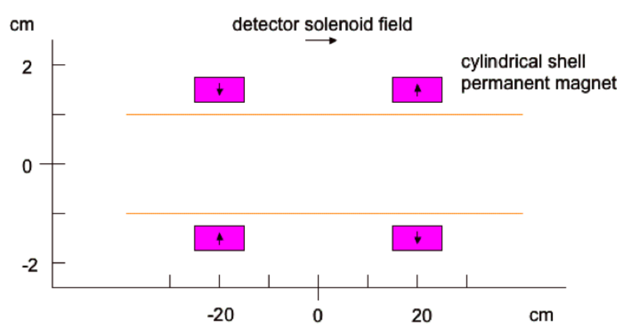

Figure 8: Radially magnetized PM cylinders near IP.

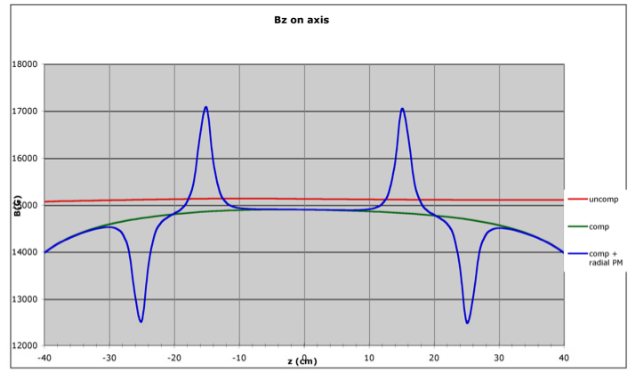

Figure 9: Magnetic field produced by radially magnetized PM cylinders near IP.

SUMMARY AND COMMENTS

Solenoid compensation implemented as close as possible to the IP, such that Eq. 1 is satisfied, provides good control of beam positions and angles through the IR and nominally removes x-y coupling. This concept should be seriously considered for new IR designs were possible.

The present analysis rests on a number of simplifying assumptions. We have assumed that quadrupoles do not steer or couple the beam, but this is not quite correct. These effects should be small, but should be investigated. We have assumed that the compensation solenoids have a circular cross-section. However, an oval cross-section is attractive since it would conform better to the IR magnet dimensions.

We have based this analysis on an early baseline design. More recent designs [4] allow less room for overcompensating the detector field, and cause more difficulty in satisfying Eq. 1. Field overcompensation will need to be done further from the IP, which will contribute to larger beam offsets and angles in the IR.

Second-order effects also should be considered. Crossing of solenoid fringe fields with an angle is expected to introduce sextupole terms that need to be estimated.

REFERENCES

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