COMPENSATION OF THE EFFECT OF A DETECTOR SOLENOID ON THE BEAM SIZE IN THE ILC*

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Abstract

In the International Linear Collider (ILC) [1] the colliding beams must be focused to the nanometre size in order to reach the desired luminosity. The method of Weak Antisolenoid is used for the compensation of the effect of the Detector Solenoid on the beam size [2], [3]. The studies of this method require the computer simulation of the charged particle's kinematics in the arbitrarily distributed solenoidal, dipole, quadrupole and higher multipole fields. We suggest the mathematical algorithm that allows to optimize parameters of antisolenoid for different configurations of Final Focus magnets and to compensate parasitic effects of the Detector Solenoid on the beam.

INTRODUCTION

In the ILC the field of Detector Solenoid (DS) couples beam's vertical and horizontal phase spaces in the interaction point (IP) and therefore degrades the projected luminosity. The ILC is designed to focus the beams at the IP to the nominal size of σ_x =639 nm and σ_y =5.7 nm, which moves the focusing quads closer to the IP. Also, ILC is supposed to be able to work in broad range of energy. Therefore, the standard methods of DS's effect compensation become less effective. The strong antisolenoids (SAS) installed on both sides of DS force one to move the final doublet quads farther from the IP, which contradicts the strong focusing. One can leave the quads in the field of the SAS and roll them with the angle of beam's coupling at their location. Nevertheless, this scheme requires mechanical readjustment of roll angle for every value of beam's energy. Finally, the coupling might be compensated by a number of the skew quads placed in specific phase advance with respect to IP, but such compensation is not local.

The Weak Antisolenoid (WAS) suggested for the decoupling of vertical and horizontal phase space both allows the strong focusing and provides for the quick readjustment of optics at various beam energies.

OVERVIEW OF WEAK ANTISOLENOID

Figure 1 shows the schematic of weak AS. The Final Doublet (FD) consisting of two quadrupoles QF1 and QD0, sextupoles SF1 and SD0 required for local chromaticity correction [4] and octupoles OC1 and OC0 is immersed in the field of the Detector Solenoid. To compensate DS effect the Weak Antisolenoid is installed in the region of main overlapping of DS field and the fields of the FD elements. The Weak Antisolenoid is aligned on the detector axis while the beamline is inclined in horizontal direction by θ_s=7 mrad with respect to the DS.

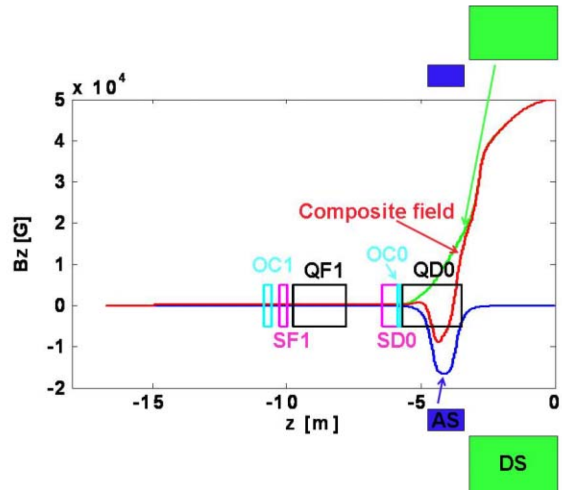

Figure 1: Final Doublet in the fields of the Detector Solenoid (green line) and the Weak Antisolenoid (blue line). The IP is at z=0 m. This plot is given for the length of the final drift L*=3.51 m and a Silicon Detector (SiD) solenoid field.

Two main adverse consequences of DS and QD0 fields overlapping are the significant growth of the vertical beam size in the IP and the vertical displacement of beam's trajectory in the IP. For instance, for one of the four detector concepts for the ILC - the Global Large Detector (GLD), the uncompensated DS field increases vertical beam size by the factor of 45 and displaces the vertical trajectory in the IP by 27 um (see Figure 2).

It was shown [2] that the proper choice of the WAS allows one both to adjust beam's trajectory and reduce beam size simultaneously. The studies of antisolenoid and optimization of its parameters require the extensive computer simulations of beam kinematics in the fields of FD elements immersed in the DS-WAS field.

ALGORITHM OF BEAM KINEMATICS' SIMULATION

Basics of the Algorithm

One of the possibilities for the simulation of the FD in the solenoid field is to use the conventional tracking code and model FD region by a sequence of short slices containing all the solenoid, dipole, quadrupole, sextupole and octupole components calculated for every slice in accordance with the position of the respective optical elements and the solenoid field map. This method was

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1-4244-0917-9/07/$25.00

successfully used in [2], with the tracking performed in DIMAD.

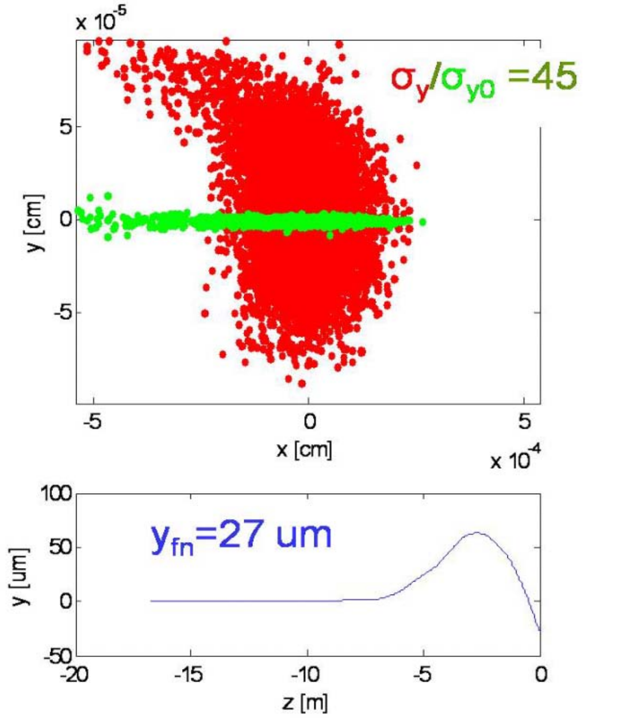

Figure 2: The effect of uncompensated DS field on the vertical beam size (upper plot) and beam trajectory in the IP (lower plot). The beam size (σ_y) is characterized by the "luminosity equivalent sigma" [5]. Green dots stand for the nominal beam profile; red dots show the uncompensated beam. These plots are given for GLD solenoid field and L*=4.5 m.

Nonetheless, we would prefer to develop the more general tracking tool that allows one to use the arbitrarily overlapping optical elements with arbitrary field profiles. To do so we adopt the approach to the beam kinematics' simulations developed in [6].

The motion of electron in arbitrary magnetic field [7] is given by Equation 1:

$$\begin{cases} x' = \theta_x, \quad y' = \theta_y \\ \theta_x = K(B_z\theta_y - \widetilde{B}_y), \quad \theta_y = -K(B_z\theta_x - \widetilde{B}_x) \end{cases} \quad (1)$$

Here x and y, are Cartesian horizontal and vertical coordinates in the beamline frame with $\vec{x}\times\vec{y}=\vec{z}$ and z axis coinciding with the direction of beam motion, $\theta_x = dx/dz$ and $\theta_y = dy/dz$, B_z is the component of solenoidal field along the z axis, $K = e/(pc)$, where e is electron charge, c is the speed of light and p is electron momentum. In our case the transverse fields are given by:

$$\begin{aligned} \widetilde{B}_x &= B_x - \frac{g_x}{2}\cdot x + G\cdot y + B_{x\,mult} \\ \widetilde{B}_y &= B_y - \frac{g_y}{2}\cdot y + G\cdot x + B_{y\,mult} \end{aligned} \quad (2)$$

Where G is the gradient of quadrupole field, B_x and B_y are x and y components of the dipole field caused by the inclination of solenoids with respect to the beamline, $g_x = B_{z\,sol}'\cdot\cos^2(\theta_s)$, $g_y = B_{z\,sol}'$, $B_{z\,sol}'$ is the solenoidal field derivative with respect to longitudinal coordinate in the solenoid frame, $B_{x\,mult}$ and $B_{y\,mult}$ are transverse fields of higher multipoles.

The application of an implicit method [8] for numerical solution of Eq. 1 in case of absent multipole fields produces the matrix equation connecting the particle coordinates' vector $\chi_n = (x_n, \theta_{x\,n}, y_n, \theta_{y_n})^T$ at the n'th step of simulation with step n+1 vector (superscript "T" means vector transpose):

$$\chi_{n+1} = M_n \cdot \chi_n + V_n \quad (3)$$

Here M_n and V_n are respectively transfer matrix and vector calculated for the n'th step. Vector V is nonzero only in presence of nonzero dipole fields. To include the dispersive effects in Eq. 3 we substitute K with $K/(1+\delta)$, where δ is electron's energy related to the nominal beam energy. Holding only first two order of magnitude terms (M_1, M_2, V_1, and V_2) in the expansion of M and V in δ we transform (3) into:

$$\begin{aligned} \chi_{n+1} &= (M_n + M_{1n}\cdot\delta + M_{2n}\cdot\delta^2)\cdot\chi_n + \\ &+ V_n + V_{1n}\cdot\delta + V_{2n}\cdot\delta^2 \end{aligned} \quad (4)$$

Eq. 4 gives the numerical solution of (1) for the regions with $B_{x\,mult} = B_{y\,mult} = 0$. In case of nonzero multipole fields we calculate χ in each step according to (4) and then simulate the effect of multipoles after each step by introducing them as short lenses.

Verification of the Algorithm

In order to verify the devised algorithm we made a set of comparisons of results of numerical simulations with predicted results in analytically calculable setups of non-overlapping quads, solenoids and dipoles. We also carried out the test suggested in [2] for WAS studies. It was shown that for the infinitely short test solenoid placed on the detector axis at distance z_s from the IP the vertical displacement of trajectory y_{fn} in the IP is:

$$\begin{aligned} y_{fn} = \frac{Bl\cdot\theta_s}{2B\rho}\sqrt{\frac{\beta_{y\,IP}}{\beta_y}}(z_s\cos(\mu_y) + \\ + z_s\alpha_y\sin(\mu_y) - \beta_y\sin(\mu_y)) \end{aligned}$$

Here Bl is the integrated strength of the test solenoid, $B\rho$ is the magnetic rigidity, α_y, β_y and μ_y are Twiss parameters at solenoid location and phase advance between test solenoid and IP, and $\beta_{y\,IP}$ is beta function at the IP [2].

Figure 3 shows the results of analytical calculations of the effect of test solenoid with Bl=0.5 T·m on the beam trajectory and results of the simulation with short solenoid having the same integrated strength.

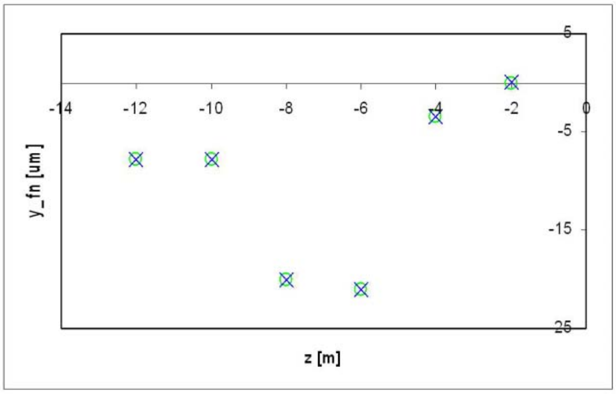

Figure 3: Vertical offset of beam trajectory in the IP depending on the position of test solenoid. Analytical results are presented by ‘o’; simulations are shown by ‘x’. Optics with L*=3.51 m and θ_s=10 mrad is chosen for this exercise.

APPLICATION OF THE ALGORITHM TO WEAK ANTISOLENOID

Realization of the algorithm described above provided us with the tool necessary for optimisation of the WAS. For instance, starting with the beam presented in Figure 2, we were able to find such AS parameters that both relative vertical size of the beam and its trajectory’s vertical displacement were reduced to 1.5 and 0.6 um respectively (see Figure 4).

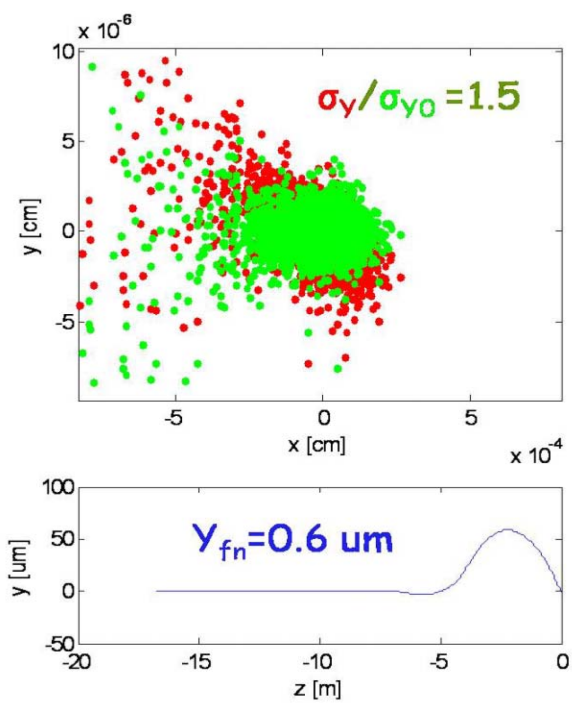

Figure 4: Beam profile (upper plot) and vertical projection of beam’s trajectory (lower plot) in the IP for GLD solenoid field compensated with Weak Antisolenoid. Green dots in the upper plot represent nominal beam; red dots stand for the compensated beam. 1E4 particles were tracked.

For this exercise we used the WAS represented by the coils of current in vacuum. The aperture of this mock-up antisolenoid is 50 cm, its length is 220 cm, the peak field is 8350 G and its centre is located at 5.46 m from the IP. The beam energy is 250 GeV. The peak field of GLD solenoid is 3 T. The physical antisolenoid is supposed to consist of several coils, which is going to make it more flexible and allow finer adjustment.

CONCLUSION

In the course of studying the compensation of Detector Solenoid effects on the beam with the Weak Antisolenoid we derived the algorithm of beam tracking in the arbitrarily overlapped fields of solenoids, quads and higher multipoles. This algorithm provides a convenient tool for optimization of Weak Antisolenoid for optics with different L* and different Detector Solenoids. As an example, we demonstrated successful compensation of the Global Large Detector solenoid field.

ACKNOWLEDGMENTS

The author would like to thank A. Seryi for fruitful discussions and many helpful suggestions, and B. Parker for providing the field maps of different detector solenoids for the studies.

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