EFFECT OF COLLIMATOR WAKEFIELDS IN THE BEAM DELIVERY SYSTEM OF THE INTERNATIONAL LINEAR COLLIDER*

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Abstract

The collimators in the design of the International Linear Collider (ILC) Beam Delivery System (BDS) may be a significant source of wakefields and significantly degrade luminosity. New simulations are used to predict the effect of BDS collimator wakefields, and compared with previous analytical methods. BDS lattices optimised for improved collimation performance are also examined.

INTRODUCTION

The ILC BDS[1][2] collimators include small aperture spoilers and several larger aperture absorbers. Each collimator will dilute beam emittance to some extent, and consequently degrade the machine luminosity. The design beam emittance for the ILC is $\gamma\varepsilon_x=10\times10^{-6}$ m.rad and $\gamma\varepsilon_y=4.0\times10^{-8}$ m.rad at the interaction point (IP).

BDS collimator wakefields have previously been studied using simple analytical models[3] to estimate the effect on beam emittance. In this paper a full beam tracking simulation with wakefields (PLACET) is used to study emittance dilution and compare with the analytical estimations.

Recent studies have been performed to improve the collimation performance of the ILC BDS lattice [4]. Both original and optimised lattices are compared here.

ILC BDS COLLIMATORS

The ILC BDS design includes two betatron spoilers (SP2, SP4), an energy spoiler (SPEX) and several absorbers and protection collimators. The protection collimators have relatively large apertures and in this paper their wakefield effects are assumed to be small and thus neglected.

Halo tracking simulations have been performed to estimate the collimator apertures required to ensure efficient halo collimation and absorption of secondary particles [5]. In these studies the collimation depth was assumed to be $9\sigma_x$, $65\sigma_y$. The main spoiler apertures and materials are given in Table 1. Most of the absorbers are copper and have full apertures of 4.0 mm. All collimators are assumed to have a very shallow taper angle of 20 mrad.

Table 1. Spoiler apertures and materials in ILC BDS.

	Full aperture x (mm)	Full aperture y (mm)	Material
SP2	1.8	1.0	Ti
SP4	1.4	1.0	Ti
SPEX	2.0	1.6	Ti

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Preliminary simulations using the optimised lattice suggest that a vertical SPEX aperture is not required to achieve efficient vertical collimation[4], although the full simulations have not yet been performed.

ANALYTICAL ESTIMATES

An outline of the analytical approach[3] to BDS collimator wakefields is given below. Only short range wakefield effects are considered. For each collimator a 'jitter amplification factor' is defined as

$$A=\frac{m}{n}=\kappa\frac{\sigma_y}{\sigma_{y'}} \quad (1)$$

and identically for the x-plane. A beam offset of $n\sigma_y$ results in an angular deflection of $m\sigma_{y'}$. κ is the collimator kick factor, which is implicitly defined by (1) as $\kappa = m\sigma_{y'}/n\sigma_y$, in other words the kick angle per unit incident beam offset.

The kick factors have contributions from geometric and resistive wakefields. They are evaluated using the theoretical expressions derived in [6] and [7]. These expressions predict that the geometric effect is dominant for ILC spoilers and absorbers. The geometric theory defines three regimes of collimator taper geometry; shallow or 'inductive', medium or 'intermediate', and steep or 'diffractive'. Within each regime the kick factor depends on beam properties (charge, energy, bunch length) and collimator properties (taper angle, gap, width). The resistive kick is evaluated separately and added linearly. Then with the known beam optics, the amplification factors can be evaluated for each collimator.

The kick varies over the length of the bunch so the mean kick factor is assumed in the calculation. If the kick is assumed to be Gaussian in *z* [8] then the variation in kick a bunch experiences is 40% of the mean kick. With this assumption, it follows that the emittance increase for a collimator is

$$\frac{\Delta\varepsilon}{\varepsilon}=(0.4nA)^2 \quad (2)$$

for $n\sigma$ incoming position jitter. The total BDS emittance dilution at the IP is then calculated by a weighted sum of the jitter amplification factors over all the collimators, where the weights are the betatron phases of the collimators with respect to the IP.

For the original BDS lattice the estimated vertical (horizontal) emittance dilution is 4.4% (0.1%) for 0.5σ

jitter. In the optimised lattice, it is assumed that the vertical aperture of the SPEX can be removed completely and the vertical emittance dilution is 0.9%. The estimated wakefield effects are dominant in the vertical plane since the vertical emittance is two orders of magnitude smaller than the horizontal.

Energy jitter can cause additional horizontal transverse jitter at points of non-zero horizontal dispersion. Thus horizontal collimators in dispersive regions can cause additional emittance increase. Taking the design dispersion at each collimator, the additional horizontal jitter and thus emittance increase can be calculated for arbitrary energy jitter. For 1% energy jitter, 2.2% additional horizontal emittance increase is estimated for both the original lattice and the optimised version.

There are several simplifying assumptions made in the analytical estimates. For example using equation (2) to combine the effect of all collimations implicitly assumes that the offset of the beam is the same in every collimator. Due to betatron oscillations and jitter amplification throughout the BDS, the beam offsets may be significantly larger or smaller than 0.5σ. Longitudinal bunch distortion due to wakefields is also ignored, which can exaggerate the effect of wakefields.

SIMULATED ESTIMATES

To test the analytical estimates with an alternative, less assumptive, approach the beam tracking simulation code PLACET[9] was used. RMS beam emittances are calculated over all particles, using $\varepsilon_x(\text{rms}) = \sqrt{<x^2><x'^2> - <x.x'>^2}$ and similarly for y. The PLACET wakefield model[8] is very similar to that used in the analytical estimates, at least for the geometric component of the wakefield.

The simulated emittance increase due to each of the spoilers is shown in Figure 1.

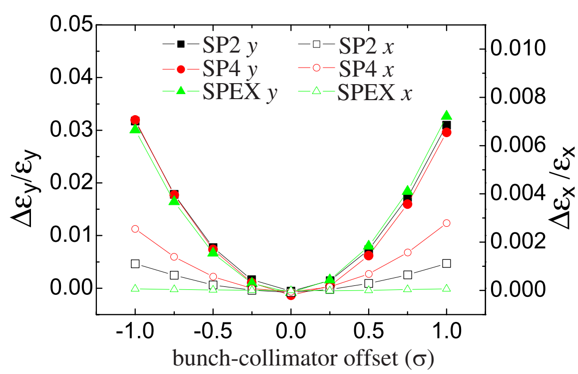

Figure 1. Emittance increase vs bunch-collimator offset for BDS spoilers.

As with the analytical estimates the vertical wakefield effects on the emittance are much larger. The vertical spoilers all have the same beam-size-normalised gap and so all three have the same emittance curve. In the horizontal, the normalised gaps differ leading to different emittance dilutions.

To obtain an estimate of the entire BDS emittance increase for 0.5σ jitter the following approach was taken. Many bunches with initial offsets and angles randomly and uniformly drawn from the interval $-0.5\sigma_y < y < +0.5\sigma_y$, $-0.5\sigma_{y'} < y' < +0.5\sigma_{y'}$ at the BDS entrance. Each bunch was tracked to the IP and the emittance increase was recorded. The emittance distributions for both the original BDS lattice and the optimised version are shown in Figure 2. The optimised lattice demonstrates significantly better performance simply due to the fact that vertical energy spoiler has been removed.

Emittance increase due to energy jitter via horizontal collimator wakefields can be studied in PLACET by simply offsetting the initial beam energy. However, chromatic and other higher order effects in addition to wakefields can cause emittance increase in the simulation. Figure 3 shows the results of tracking off-energy beams in the absence and presence of collimators and sextupoles.

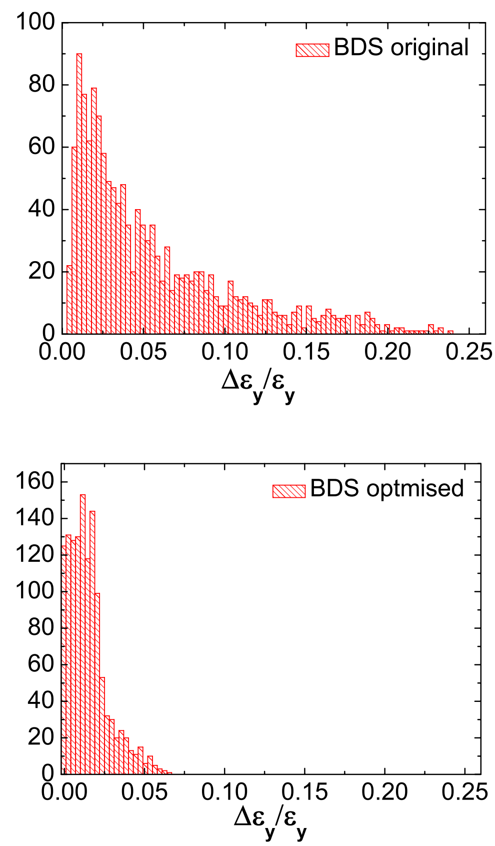

Figure 2. IP emittance distributions resulting from 0.5σ beam jitter at the BDS entrance for the original (upper) and optimised (lower) lattices.

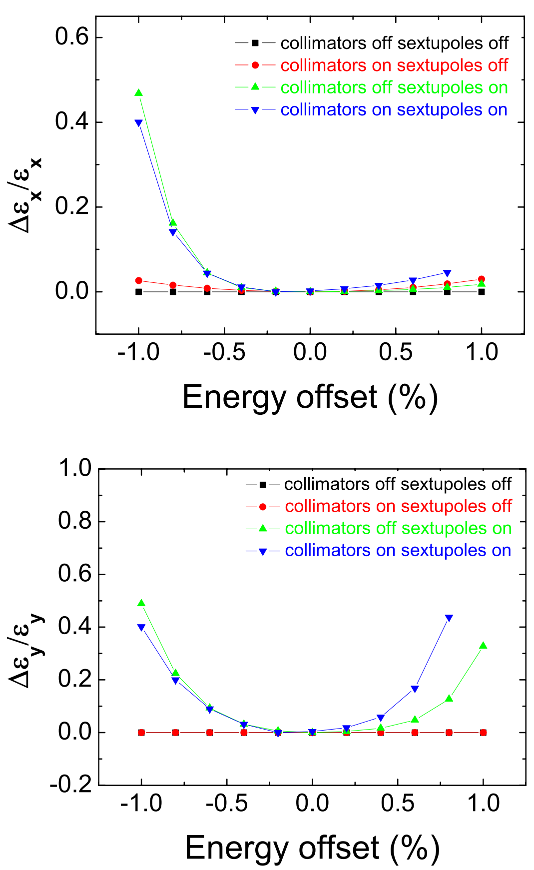

Figure 3. Emittance vs beam energy offset with horizontal collimators. In the lower plot the black and red lines overlap exactly.

The off-energy beam phase space at the IP is not elliptical and thus the emittance is poorly defined. However the ε(rms) quantity calculated in PLACET is a measure of the phase space area occupied by the beam particles and can still be used to compare wakefield effects. It can be seen that in the absence of sextupoles, collimators make relatively little contribution to emittance increase; and in the vertical plane there is no effect from horizontal collimators as expected. It is also clear that sextupoles may cause significant emittance increase in both planes for off-energy beams.

CONCLUSION

The effects of collimator wakefields in the ILC BDS have been studied in full beam tracking simulations using PLACET. The results agree with the analytical approach to within an order of magnitude.

Each BDS spoiler is estimated to increase the emittance by the order of 1% in the vertical plane for 0.5σ transverse beam jitter. The horizontal effects are much lower.

The simulations estimate that the emittance growth due to 0.5σ incoming jitter in the whole BDS including all spoilers and absorbers forms a wide spectrum of values with a maximum of around 25% (non-optimised lattice). This is to be compared with the single number of 4.4% emittance growth from the analytical estimate. The long tail in the simulated emittance spectrum is due to effects such as longitudinal bunch distortion and beam trajectory distortion. These are not accounted for in the analytical predictions and are much worse in the non-optimised lattice which has a narrow vertical gap at the energy spoiler.

The recently developed optimised lattice, in which it is assumed the SPEX can be removed completely, shows much lower emittance dilution both in the PLACET simulations and the analytical prediction.

Finally the simulations of beam energy jitter suggest that chromatic effects will dominate over wakefield effects.

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REFERENCES

[1] A. Seryi et al. “Design of the Beam Delivery System for the International Linear Collider”. PAC07, Albuquerque, New Mexico, USA. p1985.

[2] “International Linear Collider Reference Design Report, Volume 3. Accelerator”. ILC-REPORT-2007-001. http://ilcdoc.linearcollider.org/

[3] P. Tenenbaum, “Collimator Wakefield Calculations for ILC-TRC Report”, LCC-NOTE-101, SLAC-TN-03-38.

[4] F. Jackson et al. “Collimation Optimisation in the Beam Delivery System of the International Linear Collider”. PAC07, Albuquerque, New Mexico, USA. p2871.

[5] N. V. Mohkov et al, ‘Beam Collimation and Machine-Detector Interface at the International Linear Collider’. PAC05, Knoxville, Tennessee, USA, p2995.

[6] G.V.Stupakov “High-Frequency Impedance of Small-Angle Collimators”, PAC01, Chicago, Illinois, USA. p1859.

[7] A. Piwinski. Wakefields and ohmic losses in flat vacuum chambers. DESY-HERA-92-04.

[8] G. Rumolo et al. ‘Effects of Wakefields in the CLIC BDS’, EUROTeV-Report-2006-026.

[9] A. Latina et al. ‘Recent Improvements of PLACET’, ICAP 2006, Chamonix, France, p188.