WAKEFIELD CALCULATION - COMPARISON BETWEEN SIMULATION AND EXPERIMENTAL DATA*

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Abstract

In linear colliders the collimator wakefields have a significant effect on emittance growth, beam jitter and background estimates. Each simulation code models the collimator wakefields using a different approach and a discussion of the formalism for incorporating wakefields into the particle tracking code Merlin is included in this paper. Using simple collimator types we present the different predictions for bunch shape effects, and also for the wakefield kicks. These kicks are also compared with experimental results from SLAC End Station A (ESA).

INTRODUCTION

In order to prevent beam losses near the interaction region that could cause unacceptable background in the detector, collimators are placed close to the beam path. The tight apertures of the collimators cause wakefields that lead to beam jitter and emittance growth. The wakefields are separated into two components, a geometric component and a resistive component. The geometric wakefields are due to change in the vacuum chamber section at the collimator, with the walls assumed perfectly conducting. The image charge generated by a charge q displaced by y in a collimator of half gap a is equivalent to a charge q placed at a^2/y from the center of the beam axis. When the leading charge reaches the transition, the image charge stops following it and generates an electrostatic field on the particles that are behind the leading particle. The resistive wakes are due to the finite resistivity of the collimator material. For a collimator with tapering sections, both the tapered and the flat sections contribute to the resistive wall wakefields because of the finite conductivity of the material. The longitudinal component of the wakefield increases the energy spread while the transverse component causes emittance growth.

WAKEFIELD IMPLEMENTATION IN MERLIN

The collimator wakefields have been implemented in the Merlin tracking code in order to study the effect of the wakefields on the linear collider performances. The initial standard wakefield implementation in Merlin included only the monopole (longitudinal) and dipole (transverse) wakes. But because the collimator apertures are tight and particle bunches are close to the collimator edges, the near-wall wakefields play considerable role in single bunch dynamics [1]. For bunches close to the axis, the longitudinal effect is dominated by the monopole mode (m=0) and the transverse effect is dominated by the dipole mode (m=1) and when considering near-wall wakefields, higher order modes must be considered. Higher order modes were implemented in Merlin and new clases were derived in the code containing the extra feature and a detailed discussion of the implementation has been presented [2]. The formalism for wakefield implementation into Merlin makes several assumptions [3]:

- all particles are relativistic so the effect of the charges on each other is supressed by a power of γ and therefore ignored.
- the effects of the transverse velocity and acceleration are ignored (the position r' and r of the leading and trailing particle are constant).
- the collimator aperture is assumed to be circular (the half width or the half height, whichever is the smallest is treated as radius in this model).

The total wakefield effect is a sum over all multiple contributions: the summation is over all particles in a bunch slice and then over all slices for all modes. The usual monopole and dipole formulae are reproduced for m=0,1.

Geometric Wakes

At present, the code contains an implementation of a geometric wake function which corresponds to a simple collimator geometry: a collimator with an upper flat section of a given length and a smooth tapering angle. The wake function for a steeply tapered collimator moving from aperture b to aperture a is given by the following expression [4]:

$$W_m(z) = 2\left(\frac{1}{a^{2m}} - \frac{1}{b^{2m}}\right) e^{\frac{-mz}{a}}\theta(z) \qquad (1)$$

where $\theta(z)$ is a unit step function. The calculation of the geometric wakefield uses the Yokoya approximation for small tapering angle [5]. Therefore, in this particular case, the tapering angle can not be provided but the computation is correct for smooth transitions. The implemenation of the geometric wakes does not take into account the length of the upper flat section, only the beam pipe radius and the collimator half-gap are the parameters of interest.

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Resistive Wakes

For the implementation of the resistive wakes, Merlin reads tables of numerical integration of Chao's impedance formula [6]:

$$Z = \frac{2}{cb}\left(\frac{\lambda}{k} - \frac{ikb}{2}\right)^{-1} \tag{2}$$

The advantage of this implementation is that one can do more complicated formulae of the impedance for different radia, material conductivity etc.

BUNCH SHAPE DISTORSION

Merlin simulations were performed in order to determine the bunch shape distorsion in collimators. The beam was sent through the ILC-BDS beamline with an offset and the shift in the bunch centroid was recorded in all BDS collimators. One can see in Fig. 1 that for an initial offset of 1 nm the shift of the bunch centroid varies from -0.3μm to 0.9μm as the beam encounters various accelerator components in the beamline. If at the start of the BDS the beam shape was Gaussian, in the last collimators it is distorted as Fig. 2 shows. This bunch distorsion corresponds to the spoiler AB7. A highly distorted bunch at the interaction region is of great concern for the collider luminosity.

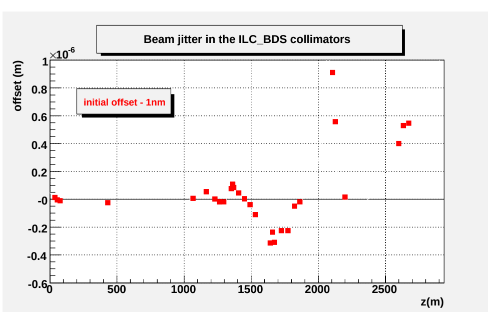

Figure 1: Beam jitter through the ILC-BDS beamline.

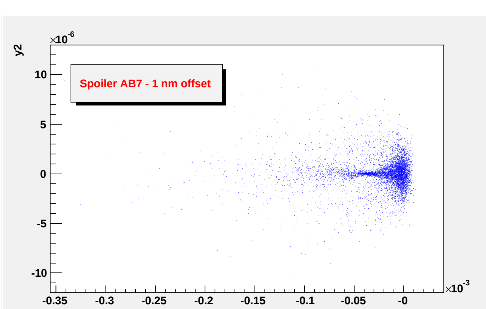

Figure 2: Beam shape is distorted in the collimator AB7.

COMPARISON BETWEEN SIMULATION AND MEASUREMENT

In order to design the ILC collimators, a goal has been set of a ∼10% agreement between the measured and predicted transverse wakes [7].

Wakefield Measurements at ESA

Wakefield measurements were performed at the Stanford Linear Accelerator Center (SLAC) at the End Station A (ESA) facility. A wakefield box was installed at ESA to test various collimators. It contains an inner "sandwich" with five slots through which the beam passes. The collimators are placed in four of them to be tested at one time while the fifth slot is used to allow the beam to pass without obstruction for other beam experiments. The collimators are placed in the beam path using a horizontal mover. The beam parameters at ESA are presented in the table.

Table 1: Specifications of the ESA beam.

Beam Property	Value
Energy	28.5 GeV
Charge	1-2$\cdot 10^{10} e^-$
Repetition Rate	10 Hz
Bunch length	0.3 - 1.0 mm
Bunch height, width	100 μm, 1 mm

The collimators tested at ESA are presented in Fig. 3, Fig. 4 and Fig. 5 and Fig. 6. They are made of copper, apart from collimators 11 and 14 which are made of titanium, and all have a smooth surface apart from collimator 10 which has a surface roughness of few μm. The dimensions are given in the pictures.

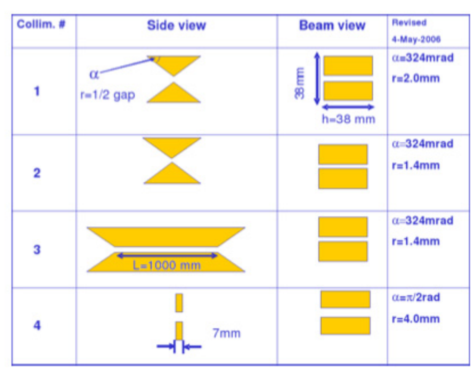

Figure 3: Beam collimators at ESA.

Merlin Predictions

Simulations were run in order to determine the geometric and resistive kick for ESA collimators. The kick was computed by dividing the shift in the mean value of y' angle multiplied with the beam energy, to the offset and bunch

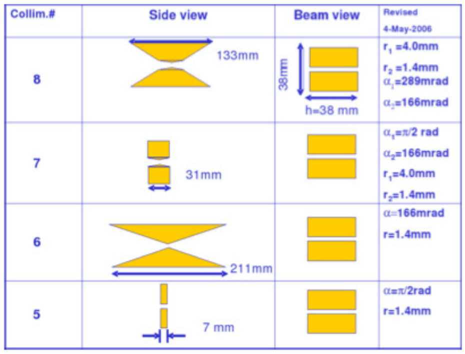

Figure 4: Beam collimators at ESA.

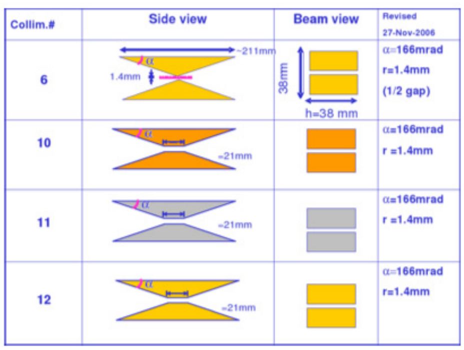

Figure 5: Beam collimators at ESA.

charge. The results are compared with the masured kick at ESA [8]:

There is a good agreement between simulation and experiment for collimators 1,2 and 3. The differences for collimators 4 and 5 can be explained by the fact that these are step collimators and Merlin assumes that they have a smooth tapering angle. These kicks are small compared to the measured kicks. For the other collimators, the Merlin predictions are bigger than the measured kicks. Merlin doesn't include surface roughness and the geometric effect is dominant.

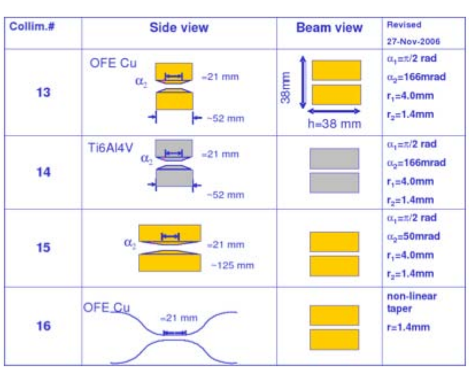

Figure 6: Beam collimators at ESA.

Table 2: Comparison between wakefield simulation using Merlin and collimator wakefields measured at SLAC End Station A.

Coll.no	Geom.kick	Resist.kick	ESA Kick
1	1.311	0.003	1.4±0.1
2	1.324	0.012	1.4±0.1
3	4.899	0.128	4.4±0.1
4	0.005	0.00004	0.9±0.2
5	0.199	0.0009	3.7±0.1
6	2.115	0.20	0.9±0.1
10	2.115	0.20	1.4±0.2
11	2.115	0.11	1.7±0.1
12	2.115	0.20	1.7±0.1

CONCLUSION

An implementation of the wakefields into the computer code Merlin has been discussed and beam jitter and bunch shape distorsion has been simulated. A comparison between the Merlin predictions ane the wakefield kicks measured at End Station A has been presented for a number of collimators. It was found that there is a good agreement between simulation and experiment and the geometric wakefield dominates. Future work includes implementation of different wake functions corresponding to more complicated collimator geometries.

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