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NUMERICAL CALCULATIONS OF COLLIMATOR INSERTIONS

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This report concerns the simulation technique for longitudinal and transverse wakes, including results for some of the proposed collimator designs tested in the SLAC end station wakefield tests. The purpose of this exercise is to verify existing simulation results and to expand the work to include the latest proposals for collimator designs. Several collimator designs including; single steps to tapered structures have been simulated and the results are presented in this paper. For most of the test pieces proposed here there are calculations of the transverse and longitudinal wake functions and the corresponding kick factor or loss factor.

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This report concerns the simulation technique for longitudinal and transverse wakes, including results for some of the proposed collimator designs tested in the SLAC end station wakefield tests. The purpose of this exercise is to verify existing simulation results and to expand the work to include the latest proposals for collimator designs. Several collimator designs including; single steps to tapered structures have been simulated and the results are presented in this paper. For most of the test pieces proposed here there are calculations of the transverse and longitudinal wake functions and the corresponding kick factor or loss factor.

INTRODUCTION

The removal of halo particles having large divergence relative to the designed path is advantageous to minimise damage and to reduce background levels in the detector. Such levels are maintained in the ILC by placing a series of collimators along the beam path prior to the collision. The presence of collimators induces short-range transverse wakefields that may perturb the beam motion and lead to both emittance dilution and amplification of position jitter at the interaction point (IP).

A beam travelling through a beam pipe of constant cross section should not excite any geometric wakefields. Due to the narrow aperture gaps a collimator will add an impedance mismatch wherever it is placed. This impedance mismatches causes reflections in the electric field which could perturb subsequent bunches.

As a charged bunch passes close to a metal surface a current/charge is induced in the surface of the metal, and a resultant electric field is produced.

This modifies the beam dynamics in two ways;

- If the distance to the charge particle is small enough then the electric field induced by the front of the bunch alters the momentum of the back of the bunch.
- If the field induced is strong enough and the fields have not diminished before the next bunch approaches then these wakefields could exchange energy with the next bunch and this effect could possibly be amplified by the second bunch, a cumulative effect.

The effects of wakefields could be longitudinal, resulting in energy spread of the beam, or transverse, providing an off-axis kick to the beam.

There are three factors which enhance the effects of wakefields, these being the geometry, the material and the surface finish. A sharp change in the impedance of the geometry would result in a larger reflection in the fields providing a large wakefield kick to the beam.

CHARACTERISATION

It is essential to understand the wakefield affects generated when introducing a set of collimators into a beam line. Due to the absence of suitable beam lines with similar characteristics to the ILC beam delivery system a technique is required to understand the luminosity degradeation for each collimator design. A fast and affordable method for characterising the effects of collimator shapes suitable for the ILC are being investigated at Daresbury Laboratory[1]. Numerical calculations have been performed on a number of collimator insertions to calculate directly the wake potentials longitudinal, and also transverse in the event of a beam offset. From this information it is possible to determine the loss factors and more importantly the kick factors imposed on the incoming beam.

Numerical calculations have been discussed previously with considerable success; however most of these calculations have been carried out on assorted models with different codes. For this investigation we have carried out a comparison of MAFIA[2] and GdfidL[3] with the same collimator shapes and initial conditions, to expand upon earlier work elsewhere [4].

Collimator Designs

The collimator shapes studied are part of the ESA Wakefield test programme at SLAC[5], a schematic of the slot type are shown in Figure 1. The two slot types shown are step collimators and tapered collimators. Table 1 describes the dimensions used for the calculations.

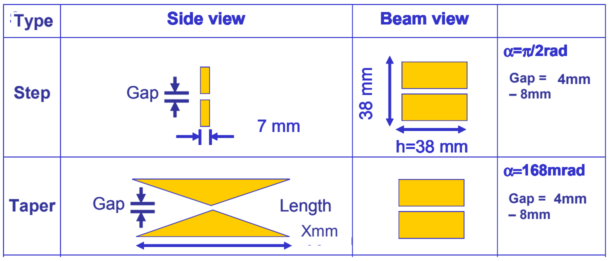

Figure 1: Collimator schematic diagram.

Table 1: Collimator jaw descriptions

Collimator	Type	Gap	Length
Slot 1	Taper	8mm	~100mm
Slot 2	Taper	4mm	~100mm
Slot 4	Step	8mm	7mm
Slot 5	Step	4mm	7mm
Slot 6	Shallow Taper	4mm	~200mm

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SURVEY OF EXISTING TOOLS

To predict the wakefields associated with various collimator designs, one must have resolution that allows the structure of bunches to play a part. In the ILC, mesh size must be <100µm in z, although making a grid which is conformal to the often shallow jaws of collimators introduces further complications related to the physical scale. The computational demands on such a solver are significant and, even though the increasing availability of 3D moving mesh solvers such as ECHO [6] may alleviate the hardware requirements, there remain significant challenges in producing accurate predictions. Our effort here is focussed on the application of existing `best practice' with MAFIA and GdfidL to these problems.

COMPARISON OF MAFIA AND GDFIDL

Hardware

GdfidL is set up on the e-science cluster at Birmingham University, where there are 54 Dual processor 3GHz, 2GB RAM worker nodes [6]. This allows us to look at problems with larger numbers of mesh cells than MAFIA, for which our PC version has difficulty addressing large amounts of memory space.

Simulation of Tapered Profile Collimators

Finite Difference Time Domain techniques are known to be most accurate when the cells have the same size in all dimensions. When we are interested in short bunches, specifically 300µm for the ILC, and structures up to metres long we find ourselves balancing the conflicting requirements of keeping the mesh 'square' and of preventing the models from becoming too big. One should be able to ensure the mesh aspect ratio is not creating unnecessary errors by checking results with a longer bunch length. This was a particular issue with the tapered collimators, the longitudinal wakepotentials for such tapered collimators are shown in figure 2.

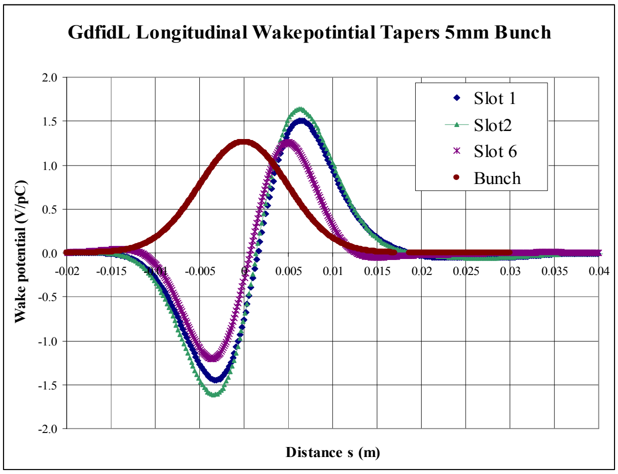

Figure 2: GdfidL Longitudinal Wake Potentials.

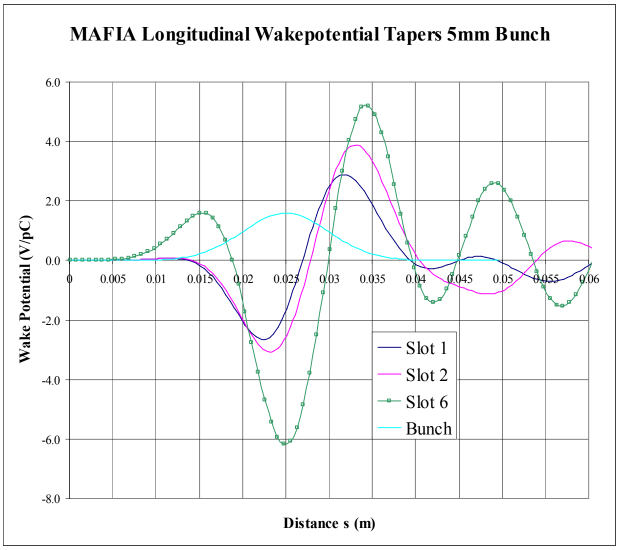

Figure 3: MAFIA Longitudinal Wake Potentials.

The mesh used for these simulations was made as similar as possible, however GdfidL was run with Napoly integration technique[7] switched on. This dampens the oscillations evident at distances greater than s=0.04m on the MAFIA plot. The GdfidL wakepotentials are also considerably smaller than their MAFIA equivalent. From previous studies with Napoly integration technique deactivated, the wakepotentials and longitudinal loss factors for the two solvers are in agreement.

Calculations of Longitudinal Loss Factor

By integrating the wake profile over the bunch distribution, we obtain the loss factor.

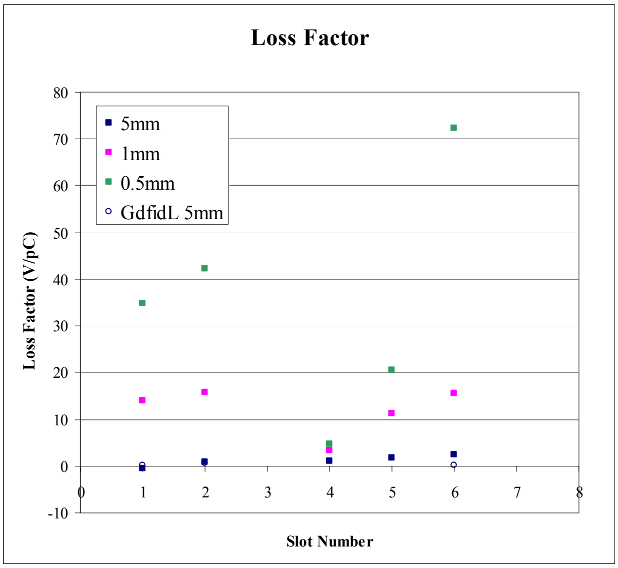

Figure 4: Longitudinal loss factor for different slots.

Figure 4 summarises the results from MAFIA (5mm, 1mm and 0.5mm bunch lengths) and GdfidL simulations (5mm bunch lengths) for a number of different slots using similar mesh settings. As can be seen from the plot there The loss factor doubles as the bunch length decreases by a factor of 10. A comparison of plots 4 and 5 confirm that the loss factor is inversely proportional to the collimator gap.

There are some concerns that the results suggest that the shallower taper (slot 6) has a larger loss factor compared with the steep taper (Slot 2), both with identical gaps for a 500 micron bunch length. For these calculations the mesh had to be reduced in the x and y plane in order to allow 5 mesh lines per bunch length. This appears to be the limit of the MAFIA calculations.

Calculations of Transverse Loss Factor

The transverse wake function and longitudinal wake function are related through the Panofsky-Wenzel theorem. This relationship is used implicitly in GdfidL to calculate the transverse loss factors and kick factors. Fig. 5 shows the loss factors calculated by GdfidL as a function of bunch offset from the electrical axis of symmetry for collimator 2 with 5mm or 1mm bunch length and various choices of mesh.

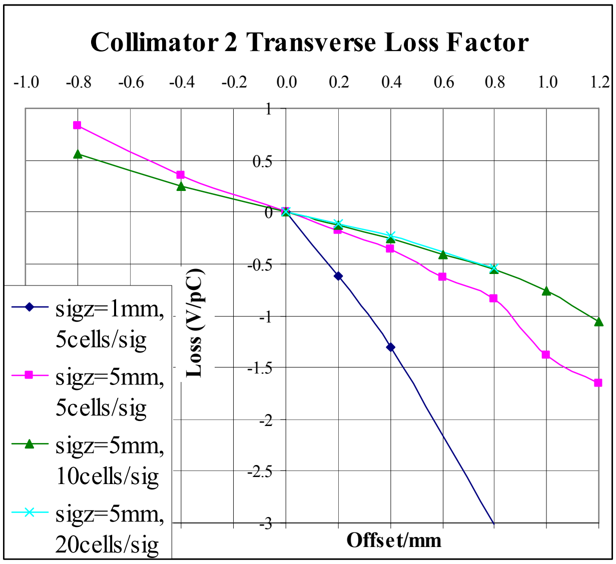

Figure 5: Transverse loss variation with beam offset.

It is clear that the shorter bunch receives a much larger kick, as we would expect. Higher resolutions have been characterised by showing the ratio between the z extent of the cells and the bunch length (cells per sigma z). We see that the higher resolution simulations reproduce the expected curve as the bunch approaches the collimator (1.4mm in this case) and that there would appear little reason to raise the mesh above 10 cells to describe the bunch.

CONCLUSIONS

The prototype collimators have been simulated in both MAFIA and GdfidL, both with longer bunch lengths and those appropriate to the ILC. Our results are summarised in Tables 2 and 3 below.

Table 2: Summary of MAFIA loss factors (V/pC)

	5mm	1mm	0.5mm
Slot 1	-0.60	14.01	34.75
Slot 2	0.89	15.67	42.16
Slot 4	1.18	3.379	4.76
Slot 5	1.70	11.254	20.57
Slot 6	2.44	15.44	72.42

Table 3: Summary of GdfidL kick factors (V/pC/mm)

	5mm	1mm	0.5mm
Slot 1	0.37	2.0	3.0
Slot 2	0.65	3.0	TBD
Slot 4	TBD	1.0	1.1
Slot 6	0.51	TBD	TBD

Here we have TBD where further analysis is required to provide a solution which is not mesh dependent.

For the ILC parameters (0.3mm bunch length), the resolution of wakepotential calculations using MAFIA on a PC based system were constrained by the memory that could be addressed.

GdfidL (located on a UNIX cluster) calculations were able to cope with the large memory demands for the ILC bunch lengths, and for this reason we recommend all future calculations to adopt UNIX based systems.

REFERENCES

[1] C.D.Beard et al,these proceedings MOPLS071.
[2] www.cst.de
[3] www.gdfidl.de
[4] N.K.Watson et al, these proceedings, MOPLS066.
[5] C.Ng et al. “Numerical Calculations of Shot-Range Wakefields of Collimators”, PAC’01, Chicago, p. 1853
[6] http://www.ep.ph.bham.ac.uk/cluster/
[7] W. Bruns “The Gdfidl Electromagnetic Field Simulator”, 2004, CERN, http://clic-meeting.web.cern.ch/clic-meeting/2005/10_07wb.pdf