EUROTeV-Report-2008-049

GDFIDL Simulations of International Linear Collider Candidate Collimator Assemblies

J.D.A. Smith, Cockcroft Institute/Lancaster University, Daresbury, UK

2008

Abstract

Collimator performance is critical to the successful operation of any collider. Building on previous GdfidL simulations of collimator jaws, this paper describes simulations where STF files of the complete assembly are investigated and wakefield performance is determined and optimised.

This report was presented in the EPAC Conference under the reference WEPP165

j.d.smith@lancaster.ac.uk

GDFIDL SIMULATIONS OF INTERNATIONAL LINEAR COLLIDER CANDIDATE COLLIMATOR ASSEMBLIES*

J. D. A. Smith, Cockcroft Institute/Lancaster University, Daresbury, UK†

Abstract

Collimator performance is critical to the successful operation of any collider. Building on previous GdfidL simulations of collimator jaws, this paper describes simulations where STL files of the complete assembly are investigated and wakefield performance is determined and optimised.

INTRODUCTION

Design of a collimator is crucial to the correct functioning of a particle accelerator. It should eliminate the beam halo, while limiting emittance growth, and yet be robust enough to handle asynchronous beam dump. This paper is concerned with the electromagnetic performance of a collimator designed for the International Linear Collider. It has been shown that GdfidL [1] is a versatile tool for investigating the wakefield performance of collimators in regimes where it is difficult to perform calculations with alternative 3D software tools such as MAFIA [2, 3]. A series of experiments using 15 prototype collimators has been conducted at End Station A at SLAC to test the validity of prevailing analytical expressions for the wakefield in these regimes [4, 5, 6], and the accuracy with which wakefields can be predicted by these state of the art numerical electromagnetic solvers such as GdfidL and Particle Studio [7]. The first part of this report concerns itself with the calculation of the wakefield performance of a complete collimator assembly. The final collimators must meet or exceed the specifications laid out in the Reference Design Report [8]. These identify parameters which have been used in particle tracking simulations to determine performance at the interaction point [9], and provide us with an upper limit on the wakefield kicks that the collimators should produce. Space is limited in the Beam Delivery System, and as a consequence it is necessary to minimise the longitudinal length of the collimation system. This trade off is investigated in the second half of this paper.

CALCULATIONS OF THE RADIO FREQUENCY PERFORMANCE OF A COMPLETE COLLIMATOR ASSEMBLY

The $10\mathrm{mm}$ beam pipe has a cut off frequency around $8.8\mathrm{GHz}$. Any modes excited below this frequency will not be able to propagate out of the collimator assembly, and will need damping by ferrites or otherwise. A study is underway to identify whether any of these modes could be problematic by causing localised heating. Fig. 1 shows the geometry in GdfidL. Also, lower frequency modes are more likely to affect following bunches. The magnitude of this effect can be qualitatively estimated by comparing the $300\mathrm{ns}$ bunch to bunch spacing with the proportion of power remaining from a previous bunch, which decays as $e^{-Q_{ext}/\omega}$, where Q_{ext} is the external quality factor, and ω is the frequency of interest. At $1\mathrm{GHz}$, a mode with $Q_{ext} \approx 300$ would be amplified enough to pose a risk of causing emittance dilution. The resonant frequencies in the range $0 - 10\mathrm{GHz}$ have been identified and simulations are in progress to identify the Q_{ext} associated with each of these modes using the procedure described by Warner Bruns [10]. With a homogenous 1mm mesh we find 45 modes below the Nyquist frequency in the open jaw case. Fig. 1 contains a vector arrowplot of the $2.9\mathrm{GHz}$ mode, which is localised outside the vacuum grating. Calculations will be performed with both closed and open jaws, and where possible benchmarks performed against other software tools such as HFSS and Microwave Studio. The Microwave Studio set up is shown as Fig. 2.

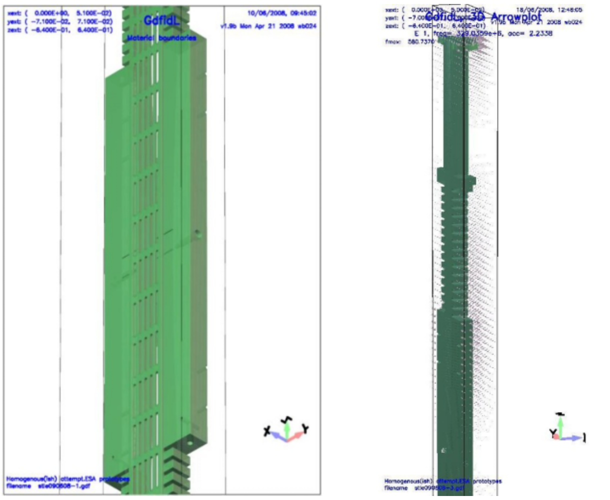

Figure 1: Collimator Assembly Geometry in GdfidL with detail of the vacuum grid, and the field pattern of the $2.9\mathrm{GHz}$ mode.

The short range wakefields have also been calculated for open jaws, at some longer bunch lengths, giving predictably small wakefield kicks of less than an order of magnitude below those for the closed jaws. These results can be extrapolated to the $0.3\mathrm{mm}$ bunch length of interest.

---

* This work is supported by the Commission of the European Communities under the 6th Framework Programme “Structuring the European Research Area”, contract number RIDS-011899

† j.d.smith@lancs.ac.uk

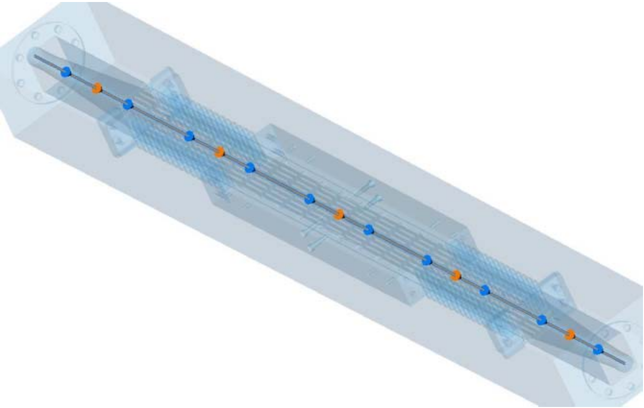

Figure 2: Collimator Assembly Geometry in Microwave Studio.

OPTIMISATION OF THE SHORT RANGE TRANVERSE KICK OF THE COLLIMATOR JAW PROFILE

For this section of the report, we turn our attention purely to the short range wakefield effects. The original parameters for the ILC jaws are those identified by Toader et al [9] based on the ILC RDR [8] to ensure the luminosity performance is achieved. These identified the most stringent collimator to have a half gap of $0.5\mathrm{mm}$ and $20\mathrm{mrad}$ taper angle. Simulations were performed with GdfidL to check agreement between numerical simulation and analytical estimate of the transverse kick. The analytic estimates for the geometric effect of such ‘intermediate’ collimators can be calculated from equation (5) in Tenenbaum et al [11], and this geometry should have a kick of $8.86\mathrm{V/pC/mm}$. This geometry was input into GdfidL and calculated with varying resolutions, and the procedure described in Smith & Glasman [7] was used, throwing away results with six or fewer cells describing the bunch length, σ_z, as their values are far from the pattern higher resolution results. The result of the convergence study is shown in Fig. 3. The numerically computed value of $8.59\mathrm{V/pC/mm}$ is in good agreement with the analytical value.

At this point, a switch to 2D geometry was made, due to the much shorter run time of two-dimensional jobs. A similar jaw with cylindrical symmetry was calculated both using GdfidL in full 3D and with the 2D code ABCI [12]. The transverse kicks of the cylindrical model in GdfidL appeared to be half of equivalent jobs with a rectangular geometry. That the ABCI result for the equivalent geometry of $2.64\mathrm{V/pC/mm}$ would be surprising otherwise. It should also be noted that the kicks increase somewhat when different solver parameters are used, giving a result closer to GdfidL. However relative kicks are of interest in an optimisation so the slower parameters were not used. Having established that ABCI was behaving reasonably in this regime, a number of jobs were submitted to the Grid to map out the kicks for collimators where two taper angles are allowed to vary, but constrained by maintaining the same inner and outer radius as the original collimator and the same length as would have been present in a $20\mathrm{mrad}$ collimator. However a flat length of $21\mathrm{mm}$ at the minimum radius of $0.5\mathrm{mm}$, which is the desired $0.6\chi_0$ radiation depth of titanium used for the spoiler was added. For each such calculation a convergence study to infinite mesh was conducted, as per the procedure above identifying the kick in the limit of cell area tending to zero. It was anticipated that the optimal angles would correspond closely to points on the optimal smooth collimator profile described by Yokoya [13]. This procedure was then repeated with a shorter total longitudinal length of $400\mathrm{mm}$ plus the $21\mathrm{mm}$ flat depth. Fig. 4 shows a contour plot of this parameter space, where deep blue represents the smallest wakefield kicks, and the black line represents the analytic optimal profile. The ABCI calculation of the kick for this profile is $2.512\mathrm{V/pC/mm}$.

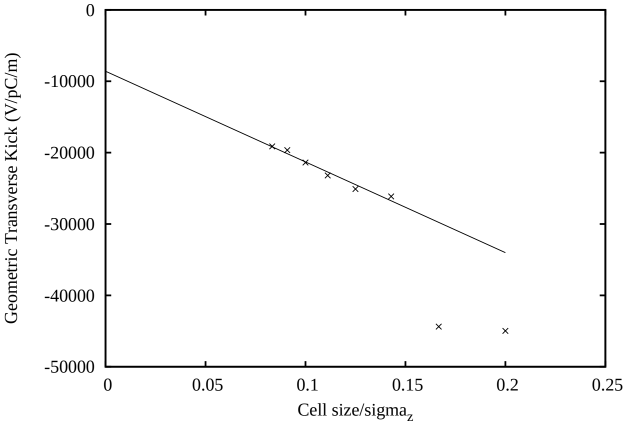

Figure 3: Convergence Study of GdfidL calculations of RDR SPEX collimator.

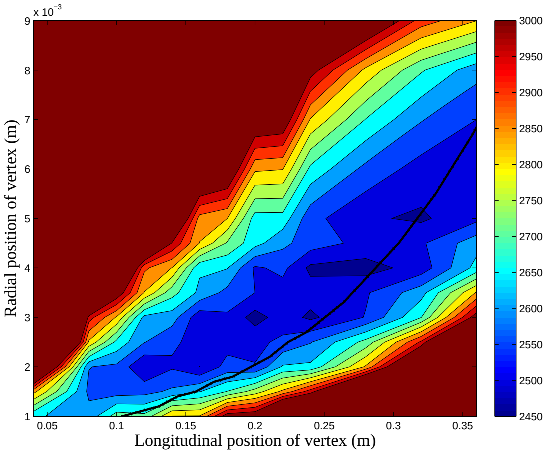

Figure 4: Contour plot showing transverse geometric kick factors as a function of vertex position for a collimator with two taper angles. The kick values shown on the scale are in V/pC/m.

A location of $r = 3.75\mathrm{mm}$ and $z = 280\mathrm{mm}$ can be selected from this figure, although further precise refinement would be possible. The kick factor associated with this revised geometry was calculated in GdfidL, both with cylindrical and rectangular geometry to quantify our improvement, and verify that it applies equally well in the rectangular case. It was also necesssary to include a flat section to house the titanium spoiler. The GdfidL results for this geometry are the same as those for the original collimator, within the accuracy of the predictions, so it is possible to shorten the collimator and accomodate an additional flat section not in the baseline design without adversely affecting the wakefield performance.

CONCLUSION AND FUTURE WORK

A complicated complete collimator assembly has been simulated in GdfidL. Eigenmodes and short range wakefield kicks have been established for an open collimator. Further numerical calculations are required to verify that there are no issues with trapped modes and localised heating while the collimators are open and when they are closed, a process including cross checking with commercial EM software tools. ABCI and GdfidL have been used to confirm the validity of analytical estimates of the wakefield kick in this regime. ABCI was used on high performance computing hardware to optimise the baseline collimator geometry. Performance similar to the original $20\mathrm{mrad}$ profile could be obtained with a flat section for the titanium spoiler in a length $75\mathrm{mm}$ shorter for both taper in and taper out. This collimator was simulated in GdfidL, and the improvement numerically verified.

REFERENCES

[1] http://www.gdfidl.de

[2] C.D.Beard and J.D.A.Smith, “Numerical Calculations of Collimator Insertions”, EPAC’06, June 2006, Edinburgh, p.709, http://www.JACoW.org.

[3] C. Beard and R.M. Jones, “Numerical Simulations of Collimator Insertions using MAFIA”, EUROTeV-Report-2006-103 www.eurotev.org/e158/e1365/e1378/e2317/EUROTeV-Report-2006-103.pdf

[4] N.K.Watson et al., “Direct Measurement of Geometric and Resistive Wakefields in Tapered Collimators for the International Linear Collider”, EPAC’06, June 2006, Edinburgh, p.697, http://www.JACoW.org.

[5] S. Molloy et al., “Measurements of the Wakefields Due to the Varying Collimator Characteristics”, PAC’07, June 2007, Albuquerque, p.4207, http://www.JACoW.org.

[6] J.L.Fernandez-Hernando et al, “Measurements of Collimator Wakefields at End Station A”, these proceedings.

[7] J.D.A.Smith and C.Glasman, “Computations of Wakefields in the ILC Collimators”, PAC’07, June 2007, Albuquerque, p.1383, http://www.JACoW.org.

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

[9] A.M.Toader et al, “Effect of Collimator Wakefields in the Beam Delivery System of the International Linear Collider”, these proceedings.

[10] http://www.gdfidl.de/HowTos/External-Q/index.html

[11] P.Tenenbaum et al, “Direct measurement of the Transverse Wakefields of Tapered Collimators”, PRST-AB 10,034401, 2007

[12] Y. H. Chin et al “ABCI Progresses and Plans: Parallel Computing and Transverse Shobuda-Napoly Integral”, PAC’07, June 2007, Albuquerque, p.3306, http://www.JACoW.org.

[13] K.Yokoya, “Impedance of Slowly Tapered Structures”, CERN-SL-90-88-AP, Jul 1990