FULL STRUCTURE SIMULATIONS OF ILC COLLIMATORS

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Abstract

The prototype collimator of the ILC is simulated, to address potential issues with trapped modes and heating. A number of codes are benchmarked, and the interplay between resistive and geometric wakefields is carefully considered.

INTRODUCTION

Collimators are critical for protecting the detectors in particle accelerators, by removing halo particles with large excursions from the design trajectory. Small aperture cause large wakefields, which can adversely affect the performance of the accelerators. Over recent years, the massive progress in computational tools has allowed the simulation of much more complex structures than was possible previously. It is possible to quickly distribute a number of similar calculations to a grid or cluster in order to rapidly optimise characteristics of the device, and we can remove some assumptions that were made to simplify the calculation.

FULL STRUCTURE DESIGN

Several options have presented for 'full structure' designs of the collimators for the ILC.[2] STL files have been created for the 'Baseline' option, with both open and closed collimator jaws. Partially open jaws have not been considered at this stage, as it is assumed the effects with be most pronounced in the extreme positions. Initially we are treating the device as a single rigid structure, made from a single material, however this would not be the case in practice. Determination of materials for such a structure may be modified in a secondary design and prototyping stage. A visualisation of the structure, demonstrating where different materials might be used is shown in figure 1.

TIME DOMAIN CALCULATIONS

Time domain codes can investigate RF structures in many way. In a whole collimator structure the relevant calculations are the investigation of quality factors of resonant modes by estimation of the wall losses and energy lost from ports of the system, and investigation the response to a prescribed ultra-relativistic source.

Knowledge of the wakefields from such a line charge can help us determine whether any of these resonant modes could couple in to the short range or extended bunch structure in such a way as to cause instability, or that sufficient power is dissipated into the support structure as to cause thermal and mechanical damage. Such coupled calculations are becoming increasingly common, and would form a natural progression to this work, however we will not consider them in this paper.

Understanding how free, radiating electrons behave in this structure is an obtainable goal that is fast becoming possible with faster computing hardware, however the assumption that one can integrate the fields experienced by the prescribed source has a wide foundation in literature, and is computationally considerably less demanding.

Computations of these complex structures do come with their own challenges. The prototype collimator design has a vacuum chamber which is 1.2 m long, 0.14 m high and 0.1m wide. The ILC bunch length is 0.3 mm, and this cannot be adequately resolved by any fewer than 5 cells, giving a 'longitudinal' cell size of 0.6 mm. Were this cell size used homogeneously across the physical domain we would have a grid of $20000\times2333\times1667$ cells, in total 78×10^{9} cells. As the components of the fields must be known at each cell, it is easy to imagine we need a computer with several TB of memory in order to compute this problem. Were these designs to be adapted for CLIC the discretization of the physical space for the FDTD technique are almost an order of magnitude greater in each dimension. In any case, we are unlikely to attempt such a calculation as the time it would take to solve would be prohibitive.

To solve this as an eigenmode problem is too time consuming even for supercomputers, however techniques exist to allow commodity clusters such as bluebear in Birmingham[3] to tackle these problems. Some of these will be described later.

EIGENMODE ANALYSIS

Methods such as the Semi Analytical Procedure (SAP) in URMEL[4] can be used to solve for the eigenmodes of a structure. The estimation of Q values is dependent on whether one is interested in frequencies above or below the cut-off of the beampipe, which as described in [1] is around 8 GHz. Furthermore, the largest dimension within which EM waves could resonate is the outer box, which at $\approx$1.2 m means we can safely treat any modes reported by a solver below 250 MHz with scepticism. Tech-X have introduced a mode frequency finding feature in their standard postprocessing toolkit with the massively parallel code VORPAL. It is intended to perform calculations with this as well as GdfidL in order to identify the modes present in the structure. We intend to tabulate Q factors, and R/Q values of modes below cut-off, where only wall losses come into play, and above cut off, where power can be lost through the beampipe to the rest of the structure. Figure 2 shows

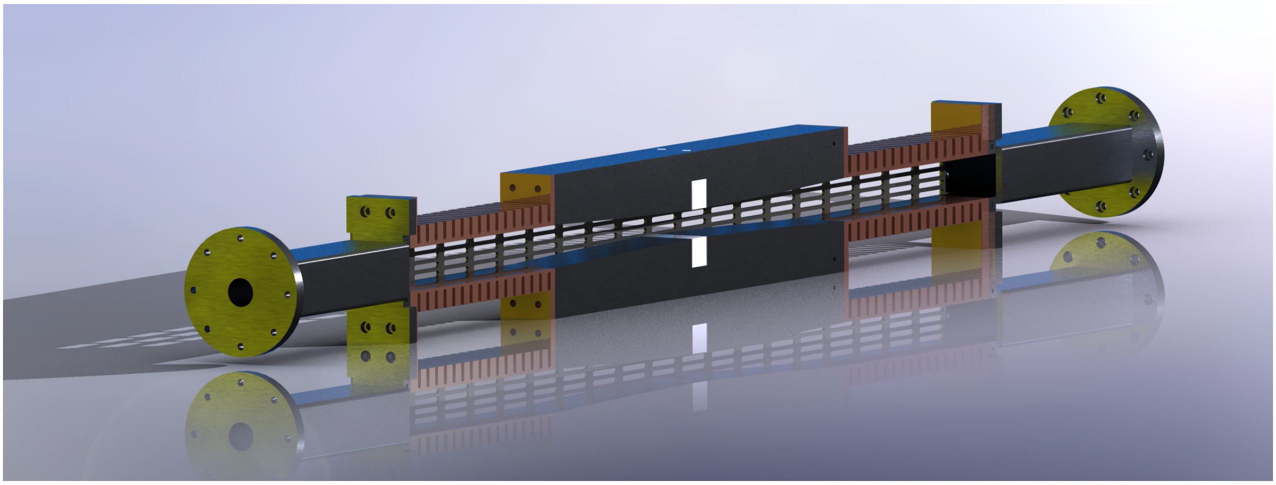

Figure 1: Impression of baseline full collimator structure with jaws open.

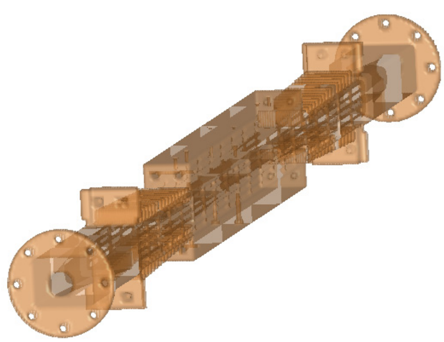

Figure 2: VORPAL screenshot showing the collimator structure.

the structure set up in VORPAL.

KICKS AT OPEN AND CLOSED JAW STRUCTURES

Calculation Techniques, and Convergence Studies

The technique of exciting a structure with a prescribed source is common to MAFIA, CST Particle Studio, GdfidL and many other codes. Consideration of potential causes for error have been discussed previously in [1]. We use a moving window around the bunch to greatly reduce the number of cells in which we need to calculate fields, greatly reducing both the memory and time requirement. Additionally we can start assuming longer bunch lengths than those for which we ultimately need to know the parameters, ensure we have agreement with analytic formulae for dependence on bunch length then extrapolate to the values we need.

Only two resolutions were used here to simulate the results, taking advantage of the experience gained on the T480 project[5], in which convergence studies have been performed on a variety of collimator type structures. The most relevant is that of the shallowest taper of the set, with the same bunch length and similar mesh. These results are shown in figure 3. That study shows that a 1mm bunch in collimator structures with 10 cells/σ_z is $\approx 35\%$ greater than the value that would be created if we performed the full convergence study, and for the same bunch length but 12 cell/σ_z results are $\approx 16\%$ too large. These are preliminary results and a full convergence study should be performed when time allows, especially as these data are for a collimator that is somewhat shallower than those in the EUROTeV report, and also a somewhat more skewed aspect ratio has been used in obtaining these results.

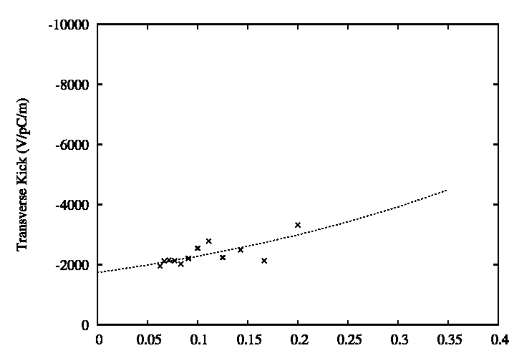

Figure 3: Convergence study for T480 collimator ‘6’, with 0.166 mrad taper angle, 1 mm bunch and small offset from the axis relative to the jaw size.

Open Jaws

Experience has shown that calculations with GdfidL are simpler to perform away from metallic surfaces. This has been borne out by a short series of simulations. For 1mm bunch length, calculations were performed at various offsets of the beam from the axis, for resolutions of 10 and 12 cells/σ_z. These results are summarised in Table 1

Table 1: Open Jaw Calculations

Beam offset from axis (mm)	resolution (cells/σ_z)	Transverse Kick (V/pC/mm)
0.25	10	0.0527
0.50	10	0.0526
0.75	10	0.0527
1.00	10	0.0530
0.20	12	0.0467

Considering our convergence data, we would expect a kick of 0.04 V/pC/mm. As one would expect these kicks are small, and of greater concern would be large longitudinal wakes. At $\approx$1.3 V/pC for our 1mm bunch, it would appear these are not of particular concern, however a shorter bunch may be able to interact with the vacuum gratings. Were this to be the case, modification of the grating should be straight forward.

Closed Jaws

Calculations at 10 and 12 cells per sigma have been performed with much squarer aspect ratio than was used for the open jaw calculation. As identified, our structure must beat the budget imposed by the work by Toader et al.[6]. Our calculations have been performed with a considerably longer bunch than that will be present, so for the calculations presented here, we must assume the inverse square root dependence on bunch length in equation (5) of Tenenbaum[7]. Figure 4 shows the longitudinal loss of the 1 mm bunch with a small offset and figure 5 shows the transverse wake.

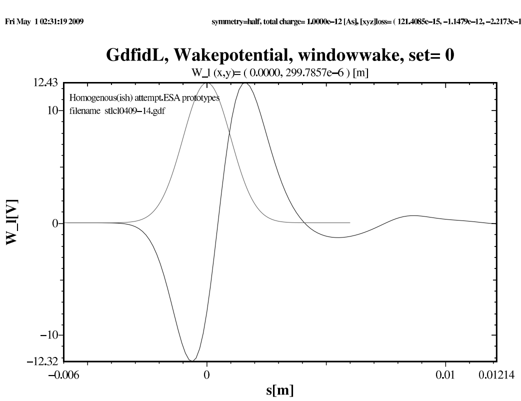

Figure 4: Longitudinal wakefields excited by a bunch of 1 mm in a complete collimator with closed jaws.

In practice it is observed that with a crude mesh the transverse loss increases rapidly with distance from the axis, and further simulation is required to determine accurately the transverse kick factor. More accurate simulations are

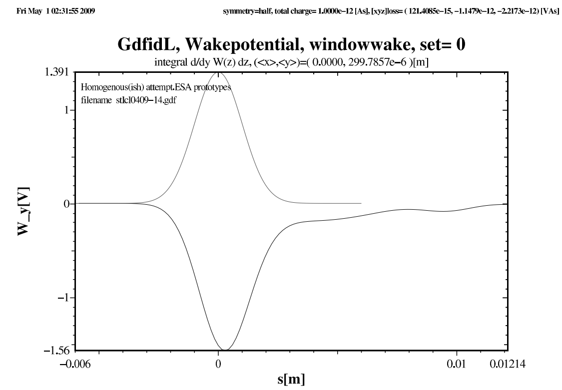

Figure 5: Transverse wakefields excited by a bunch of 1 mm in a complete collimator with closed jaws.

planned for the future. It does appear, from these initial results, that the transverse kick is well within the 8 V/pC/mm budget implied in [1]

CONCLUSION

An overview of the calculation techniques to determine RF properties of complete collimator assemblies has been presented, along with examples showing their application. Calculations with open and closed jaws have been undertaken in order to give advance warning of issues that may exist with these structures in operation. Further study with simulation tools and mechanical prototypes will be necessary before collimators are ready for the ILC or CLIC.

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