TESLA INJECTOR SIMULATIONS WITH MAFIA*

P. Schütt, T. Weiland
Darmstadt University of Technology, Fachbereich 18,
FG Theorie Elektromagnetischer Felder, Schloßgartenstraße 8, 64289 Darmstadt, Germany

Abstract

The TESLA Test Facility (TTF) is a test bed for the superconducting option of a linear e+/e- collider in the TeV regime. The injector delivers a 20 MeV beam with 1 nC charge per bunch of 1 mm length. It consists of an RF-gun, a superconducting 9-cell Capture Cavity and a chicane bunch compressor. The MAFIA modules TS2 and TS3, the particle in cell programs in 2D and 3D, as well as the module L, a tracking program, have been used to study the particle dynamics in the TTF, e.g. the emittance growth due to space charge effects in the bunch compressors. Dedicated interfaces for the three different simulation tools allow to study components separately and to hand over beam data from one accelerator section to another or one simulation tool to another, respectively.

1 INTRODUCTION

A typical linear accelerator consists of a diversity of components, which are usually developed with different design tools. When the beam dynamics in an accelerator is studied, the low energy part near the particle source usually requires the use of a simulation program that includes the calculation of space charge forces. On the other hand, the tracking of ultrarelativistic particles can be done much faster with a different class of simulation codes.

Problems may arise when parameters of the beam must be communicated between the different programs. Often, definitions e.g. for the units of the emittance differ. More over, beam models may be different: e.g. macroparticles in one code versus gaussian bunches in the next.

Within the electromagnetic CAD package MAFIA[1], three solvers are offered which allow the simulation of the full electrodynamics in the low energy part of the accelerator as well as the fast tracking in the high energy part. Interfaces are being developed to ease the handover of parameters from one code to the next.

In the low energy region, a handover of beam parameter from one accelerator element to the next is challenging even in the case where both are handled in the same code. This is due to the fields which accompagny the beam and must be interpolated from one calculation grid to the other without inducing numerical noise.

The status of this project is described in this paper.

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2 SIMULATION TOOLS

2.1 MAFIA-TS2 and -TS3

TS2 and TS3 are the names of the Particle in Cell (PIC) modules in MAFIA. They have been used successfully for the computer aided design of klystrons and other RF sources[2]. The PIC programs solve Maxwell's equations in the time domain with a FDTD algorithm and in parallel, selfconsistently, integrate the equations of motion of the charged particles. These particles, in turn, are the source of the electromagnetic fields.

TS2 is the axisymmetric, two dimensional version, TS3 works with three dimensional cartesian coordinates. Both are fully relativistic and due to their basic physics algorithm a priori include all interaction of the charged particles and electromagnetic fields. Therefore, space charge, self magnetic fields, wake fields etc. are all included. Furthermore, both codes can use precalculated static and resonant fields, which are provided by other solvers in the MAFIA package.

2.2 MAFIA-L

L is a specialized module for the tracking of relativistic particles in an accelerator. It has been used to study single bunch and multibunch instabilities[3]. Featuring a modular description or the accelerator, including alignment errors, as well as optimization strategies, it is a tool for the overall design of a linear accelerator. The statistical description of the beam allows an uncorrelated energy spread and a phase jitter.

L calculates the longitudinal as well as the transversal dynamics of the beam. It includes realistic external fields. The transversal space charge forces may be calculated in a fast approximation, wake fields can be included by a quasi Green's function algorithm, where the Greens functions are provided by MAFIA-T2.

2.3 Interfaces

Several interfaces have been developed to facilitate the data exchange from one accelerator section to the next.

If both sections are calculated by L, the data exchange is trivial: beam data can just be reused.

In the case of the PIC codes, it is necessary to store not only beam data but also the field data for one period in a steady state. Furthermore, to avoid noise in the downstream component, the beam current must be artificially raised to its nominal value over several RF periods. The algorithms for interfaces from TS2 to TS2 or TS3 have been published earlier[2].

Especially for the use in accelerator design, an interface from TS2 to L has been developed. This requires the translation between two different beam models: in TS2, the beam is described by a number of macro particles, characterized by their position and momentum at a fixed time. In L, the bunch at a fixed position in the accelerator is described by a number of time slices. These slices are characterized by their first and second order statistical moments of transversal position and momentums as well as their energy and their longitudinal position in time.

The interface has been built into TS2. During the calculation, all particles are registered when they cross the monitor plane, which is located at the beginning of the structure to be simulated in L. The slice parameters for L can then be calculated via statistics formulae. In order to keep as much information as possible, no further smoothing of the data is used.

It will rarely be necessary to hand data from L to TSx. But it can be useful to calculate single elements without the calculation of all upstream components in TSx. In order to facilitate the input of starting parameters, we plan to enable the input of Twiss parameters into TSx and to develop an interface from L to TSx.

3 NUMERICAL RESULTS

3.1 *Injector Layout*

Figure 1 shows schematically the layout of the TESLA FEL injector. A Laser RF gun delivers a beam with about 5 MeV. In a first superconducting TESLA structure, the capture cavity, it is accelerated to 15 - 20 MeV, then longitudinally compressed in a chicane and delivered to the first complete TESLA module.

The beam dynamics in the gun and possibly in the capture cavity must be simulated in TS2, because of the strong collective forces. Either at the end of the gun, or at the end of the capture cavity, L may take over.

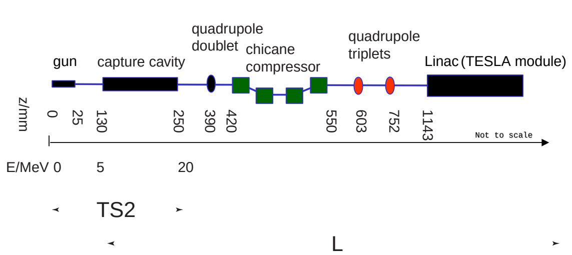

Figure 1: Schematic Layout of the Injector. The application regions of the MAFIA modules TS2 and L are indicated.

3.2 *The Gun*

Simulation results for the TESLA TTF gun have been published elsewhere [4]. For a correct treatment of the collective forces, a very fine resolution of the calculation grid is required: typically $\Delta z = 20\mu m$. The results have been compared to PARMELA calculations: when wake fields are artificially suppressed in MAFIA-TS2, both codes give the same results.

3.3 *The Capture Cavity*

The capture cavity has also been simulated with TS2 (see figure 2, next page). Since the spatial bunch dimensions are bigger here than in the gun, the resolution may be somewhat coarser: we used $\Delta z = 100\mu m$ and $\Delta r = 120\mu m$.

In order to reduce the numerical noise in the calculation, data were not taken from previous calculations, but initialized at the entrance of the cavity. The bunch length was $\sigma_z = 800\mu m$, the radius $\sigma_r = 600\mu m$. In the test case, we used an injection phase of $\Delta\varphi = -10°$. The start energy was 5.3 MeV with an uncorrelated energy spread of 13.3 keV. The maximum field amplitude in the cavity was 15 MeV/m.

3.4 *Handing Data over to L*

Close to the end of the capture cavity, an interface to L was placed in the TS2 simulation.

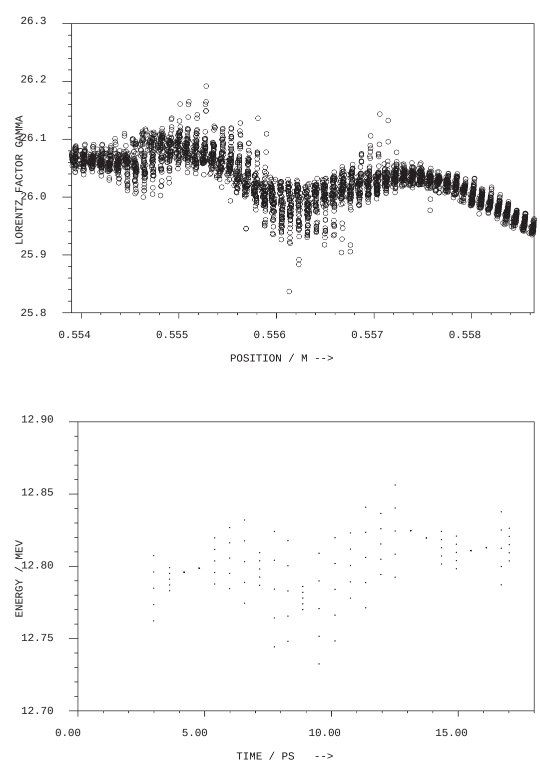

Figure 3: Energy distribution in the bunch at the end of the TS2 simulation (top) and at the start of L (bottom).

Figure 3 shows the energy distribution in the bunch as represented in TS2 and in L. In the TS2 graphic, the bunch moves from left to right, so the head of the bunch is on the right. In L, the energy is plotted as a function of time, therefore the head of the bunch is on the left. Slices in L

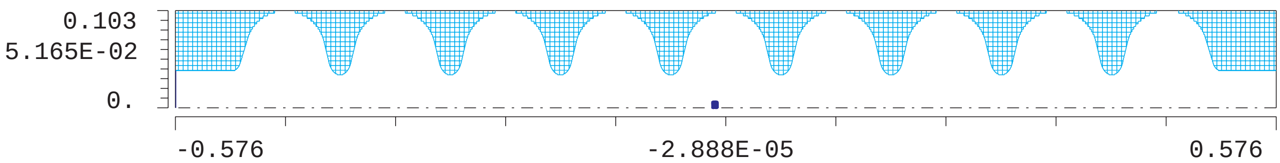

Figure 2: Capture Cavity as simulated in TS2. The structure is rotationally symmetric, the bottom line is the axis of rotation. The spot near the center shows the tiny dimensions of the electron bunch that moves along the axis from left to right.

carry different charges. The number of slices was chosen very high. Statistics is better for fewer slices at the cost of details in the distribution.

4 CONCLUSION

MAFIA provides tools to simulate the low energy part of a linear accelerator as well as a fast calculation of ultra relativistic particles with some approximations. Interfaces allow to use the result of one calculation as starting conditions for the next one.

5 ACKNOWLEDGEMENT

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6 REFERENCES

[1] The MAFIA collaboration, *User's Guide MAFIA Version 4.00*, CST GmbH, Lauteschlägerstr. 8, D-64289 Darmstadt, Germany

[2] U.Becker, M.Dohlus, T.Weiland, *Three Dimensional Klystron Simulation*, Particle Accelerators, 1995, Vol. 51, pp. 135-154

[3] M.Drevlak, *On the Preservation of Single- and Multi-Bunch Emittance in Linear Accelerators*, Thesis, DESY 95-225, Nov. 1995

[4] M.Zhang, P.Schütt, *TESLA FEL Gun Simulations with PARMELA and MAFIA*, Proc. of the 1996 Computational Accelerator Physics Conference, Williamsburg, Virginia, September 1996