CODE COMPARISON FOR SIMULATIONS OF PHOTO-INJECTORS

C.Limborg*, Y.Batygin, SLAC 2275 Sand Hill Road, Menlo Park , 94025 CA, USA

M.Boscolo, M.Ferrario, V. Fusco, C.Ronsivalle,

INFN-LNF, Via E. Fermi 40. I-00044, Frascati (Roma), Italy

L.Giannessi, M.Quattromini , ENEA Research Center Via Enrico Fermi 45, 00044 Frascati , Italy

JP.Carneiro, K.Floetmann, DESY, Notkestrasse 85, 22603 Hamburg, Germany

Abstract

RF photo-cathode injectors constitute one of the key components of many future single pass FEL based synchrotron radiation sources. The possibility of reaching very high brightness beams had been anticipated by using various simulations tools. Several experiments have proven that the 1mm.mrad normalized projected emittance for 1 nC, 10 ps pulses is within reach. For optimizing these photo-injectors, a first search of parameters is efficiently performed with HOMDYN. Further refinement in the tuning is usually obtained using a multi-particle tracking code such as ASTRA, PARMELA or BEAMPATH. In this paper, we compare results from HOMDYN, ASTRA, PARMELA, and BEAMPATH for the cases of an S-Band photo-injector. Limitations in their accuracy and differences between the codes are discussed.

1 MOTIVATION

Many codes are available for studying the dynamics of intense electron bunches at low energy in the space charge dominated regime. Newcomers in the field often ask which code to use to start studying a system based on a photo-cathode RF gun. In this paper, we compare codes which use five very different algorithms to compute the space charge: a code which solves the envelope equation HOMDYN [1], a Cloud-In-Cell (CIC) code BEAMPATH [2], a ring based algorithm PARMELA[3] and ASTRA[4], a fast Particle-In-Cell (PIC) algorithm for PARMELA spch3d and and a Lienard-Wiechert potentials approach for TREDI [5]. The test problem studied consists in an S-Band RF gun, a compensation solenoid and a drift. Quantities of interest such as rms beam size, emittance bunch length could be matched for all those codes when optimal running conditions.

2 DESCRIPTION OF CODES

HOMDYN

HOMDYN relies on a multi-envelope model based on the time dependent evolution of a uniform bunch[1]. The basic approximation, in the description of the beam dynamics, lies in the assumption that each bunch is represented by a uniformly charged cylinder whose length and radius vary, assuming a uniform charge distribution inside the bunch. The HOMDYN algorithm is very efficient and despite some strong simplifying assumptions it allows the quick relaxation of the large number of parameters involved in parameter studies, to quickly find a reasonably optimized configuration.

BEAMPATH

BEAMPATH is used for 2D and 3D simulation of axial-symmetric, quadrupole-symmetric and z-uniform beams in a channel containing RF gaps, radio-frequency quadrupoles, multipole lenses, solenoids, bending magnets, and user-defined elements. The space charge potential of the beam is calculated from the direct solution of Poisson's equation by cloud-in-cell method in a moving system of coordinates with Dirichlet boundary conditions at the aperture and periodic conditions in z-direction. Simulation of the beam with large energy spread is performed utilizing Green function method for interaction of particles with individual energies. To simulate particle emission in RF photoinjector, the code was updated by an additional space charge routine which solves Poisson's equation inside a cylindrical iron box. This approach automatically takes into account image charges arising both from injection plane and from surrounding aperture.

PARMELA / ASTRA

PARMELA and ASTRA compute the space charge force by Lorentz-transforming the particles positions and field maps into the average rest frame of the beam. It then applies static forces to the various rings of the cylindrical map assuming a constant charge density inside a ring. This algorithm requires to have at least 5 particles in each of the cell of the cylindrical grid.

PARMELA /SPCH3D

The SPCH3D algorithm of PARMELA-LANL is based on a fast Fourier Transform set on a 3D grid over which the electric field is solved to verify Poisson's equation [6]. It is quite time consuming as it requires running at least

* Contact : limborg@slac.stanford.edu,

SLAC is operated by Stanford University for the Department of Energy under contract number DE-AC03-76SF00515

100k particles and small aspect ratios of the cell dimensions. This algorithm is nevertheless necessary to be used when the aspect ratio horizontal to vertical of the beam is more than 2 and when the transverse profile does not have a cylindrical symmetry. The automated remeshing is included when using this algorithm.

TREDI

TREDI is a fully three dimensional Monte Carlo code devoted to the simulation of beam dynamics. Space charge fields can be evaluated in a point to point or point to mesh & interpolation mode, calculating the fields according to the Lienard Wiechert formalism and taking into account the effects due to the finite propagation velocity of signals. This is accomplished by storing the histories of macro-particles, and by tracking back in time the source coordinates until a retarded condition is fulfilled. Short bunch injector simulations (as the test case) can be run also in a faster “Static” mode, where instantaneous signal propagation is assumed. The “Retarded” mode allows the simulation of a wider class of problems such as CSR effects in bendings.

3 PROBLEM DESCRIPTION

The test problem consisted of simulating a S-Band gun with an emittance compensation solenoid and a drift for a 10ps square pulse, 1 mm uniform transverse laser pulse producing a 1 nC charge. No thermal emittance was included. The solenoid was set to 2.541 kG.

The first difficulty in performing such comparisons consists in implementing exactly the same maps of fields (electromagnetic for the gun field and magnetostatic for the solenoid). All of the five codes studied can translate outputs from SuperFish and Poisson. So identical maps were used. The second difficulty consists in using the same starting conditions. Each of the codes has its own launching conditions. To check that starting parameters were in agreement for all codes, we compared energy and beam sizes output for cases run without space charge. A very good overlap was obtained with the 5 codes. We could then study the single impact of the different space charge algorithms.

4 RESULTS OF COMPARISONS

Good agreement inside gun

The rms quantities beam size, emittance, bunch length and energy spread could be matched exactly for all the 5 codes inside the gun. The rms beam size obtained at the gun exit was slightly smaller with HOMDYN, see figure 1. The differences become larger in the drift which follows.

Some disagreement in drift

The local maximum in emittance around 1.5 m shows at 1.2 m in HOMDYN but around 1.5 for all the other codes, See figure 2. The first local emittance minimum is nearly identical for the multiparticle codes and the agreement is not as good for the second minimum. The energy spread from HOMDYN is closer to that of the other codes if only the core slices are taken into account for the comparison.

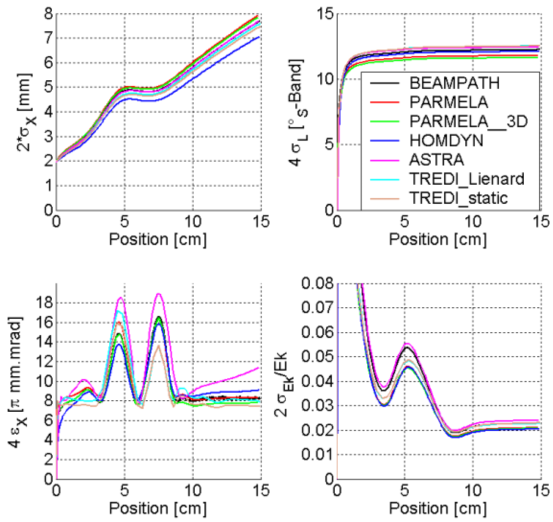

Figure 1.Comparison of evolution of rms beam size, bunch length, emittance and energy spread inside gun for the 5 codes

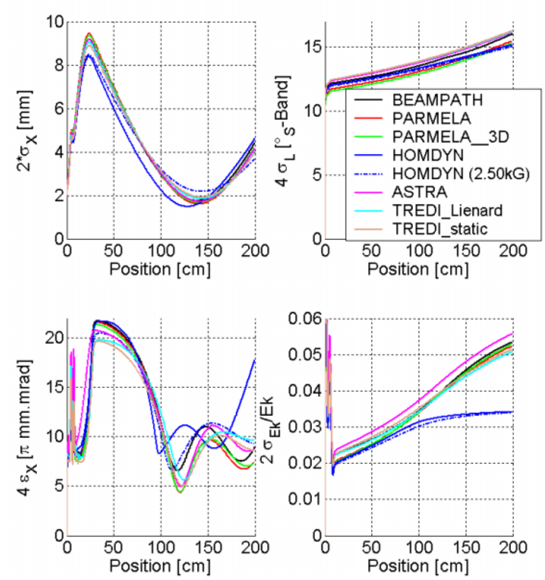

Figure 2.Comparison of evolution of rms beam size, bunch length, emittance and energy spread up to 200 cm for the 5 codes; second HOMDYN case run with solenoid reduced from 2.541kG down to 2.5 kG

5 MESHING IN TIME AND SPACE

Results depend strongly on the meshing used for the CIC code and for the SCHEFF algorithm. As a rule of thumb, each mesh should contain about 5 particles.

Table 1 – Comparison CPU time

Code	Platform	CPU	Num. particles	Mesh points N_r x N_z	Mesh size h_r x h_z	Integration step	CPU time (s)
HOMDYN	PC Win		75 slices			0.13 °	45
BEAMPATH	PC Win	1 GHz	10^4	256 x 2048	50x50µm^2	0.1° , 1°	8000
PARMELA	"	1 GHz	2.5 10^4	25 x 75	"	"	9846
" spch3d	"	1 GHz	10.10^4	32 x 32 x 1024	Automatic	"	1.4.10^4
ASTRA	"	1.8 Ghz	1.5 10^4	20 x 60	Automatic	Adaptative	420
Tredi Stat.	16 nodes	1.8 GHz	5.0 10^4	20 x 30	Automatic	Adaptative	7.5 10^3
Tredi Lien.	PC Win	1.8 GHz	5.0 10^4	20 x 30	Automatic	Adaptative	7.4 10^4

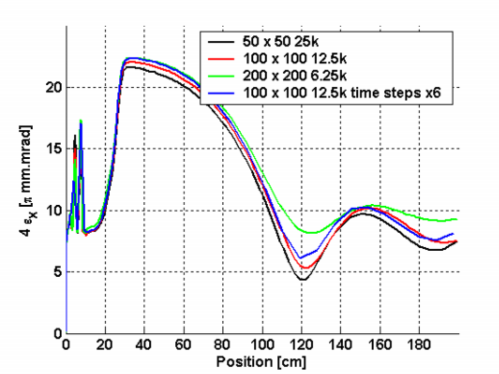

Figure 3. PARMELA results for the different meshes described in Table 2; Only the emittance varied for those 4 different cases, other parameters stayed constant

Table 2: PARMELA CPU Time on 1GHz PC

time	SPACE Mesh.	TIME Mesh.	Particles
9846 s	50 x 50 µm^2	1100, 0.1° then 1°	25 k
1286 s	100 x 100 µm^2	1100, 0.1° then 1°	12.5 k
445 s	200 x 200 µm^2	1100, 0.1° then 1°	6.25 k
345 s	100 x 100 µm^2	505, 0.2° then 1°	12.5 k

6 PHYSICS REPRESENTED

INITIAL ACCELERATION

A comparison of the dynamics between PARMELA and PIC codes [7], has shown that:

1- the image charge model is good enough to represent the boundary conditions at the origin
2- the computation of space charge forces, performed in the frame of the center of mass of the bunch in PARMELA type codes, when the Lorentz factor is small give good enough results compared with PIC or Lienard-Wiechert codes
3- neglecting the radial force generated from the beam self-induced azimuthal magnetic field does not affect the results

It was confirmed with BEAMPATH and TREDI that the approximation described in the second is correct. In TREDI the approximation is simply not used and BEAMPATH can perform computations using a Poisson solver for which individual energies are taken into account. The use of this solver for the first few mm is very time consuming but did not change the results at the end of the gun.

THERMAL EMITTANCE

In each of these codes the initial distribution can be given such that a thermal emittance is included. None of the codes include the physics involved in the generation of that thermal emittance. This is one of the key issues of the RF-Cathode gun to be tackled.

SHOTTKY EFFECT

ASTRA is the only code which includes this effect.

LONGITUDINAL PROFILE

Each of the codes can include the rise and fall time of the initial pulse but HOMDYN.

TRANSVERSE NON-UNIFORMITY

When the transverse profile does not have cylindrical symmetry, only 3D space charge algorithm should be used as in TREDI or PARMELA in the spch3d mode. ASTRA is being upgraded to offer a similar possibility.

PARMELA-UCLA and PARMELA-LANL include the possibility of using 3D maps of fields. It was checked [7] that the quadrupole moment present in the S-Band gun to be used for LCLS has negligible effects in the dynamics of the beam.

REFERENCES

[1] M.Ferrario, HOMDYN code : http://www.slac.stanford.edu/pubs/slacpubs/8000/slac-pub-8400.html

[2] Y.Batygin, "Particle-in-cell code BEAMPATH for beam dynamics simulations with space charge", ISSN 1344-3877, RIKEN-AF-AC-17 (2000), 81 p.

[3] L.Young, J.Billen , PARMELA, LANL Codes, laacg1.lanl.gov/laacg/services/parmela.html

[4] K.Floetmann,ASTRA, http://www.desy.de/~mpyflo/Astra_dokumentation/

[5] F. Ciocci, L. Giannessi, A. Marranca, L. Mezi, M. Quattromini, Nucl. Instr. & Meth. A 393, 434 (1997)., Web site: http://www.tredi.enea.it

[6] R.Ryne et al., Proc. 1998 Linac Conf., Chicago,IL

[7] E.Colby, et al."Simulation Issues for RF Photoinjectors" 7th Computational Accelerator Physics Conference, Michigan State U. Oct15-18-2000