Codes comparison in RF-GUN simulations*

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Abstract

For comparison of the 3 codes: ATRAP, ITACA and PARMELA, we choose a "geometry independant model" with external RF and magnetostatic fields analytically specified. We do this comparison for high charge bunch at moderate accelerating gradient and low charge bunch at high accelerating gradient.A set of parameters are plotted along the structure as a function of the average bunch position, like rms beam radius, rms bunch length and normalized transverse rms emittance. We obtain a good agreement in results, with difference between CPU times. An important point seems generation of particles, as well as time and space step resolution for very low emittance space charge dominated beams.

1 INTRODUCTION

We present a comparison of the results given by 3 numerical codes :

ATRAP (Accélération et TRAnsport de Particules), based on Liénard-Wiechert potentials developed by J.L. Coacolo and J.M. Dolique [1]

ITACA (Integration of Transients in Axi-symmetrical Cavities for Accelerators), PIC code developped by L. Serafini. [2]

PARMELA (Phase And Radial Motion in Electron LinAcs), particle pushing code developped at Los Alamos, implementation of B. Mouton in Orsay [3]

The aim of this work is to determine reliability range of each one, and find major reasons of the divergence if they have.

2 PARAMETER SETS USED FOR CODE COMPARISON

The geometry of the accelerating structure is taken to be a cylindrical uniform pipe (R = 30 mm) so that the wake-field effects from the irises are neglected, just the interaction with the cathode metallic wall is represented. The cathode position is at z = 0.

The intensity of the laser pulse is taken as gaussian in time and radius, described up to 3 σ. The injection phase ϕ_0 is the time when the head of the laser pulse, at 3 σ from the center, hits the cathode surface.

The RF field specification are :

$$E_z = E_0 cos(kz) sin(\omega t + \phi_0)$$

$$E_r = \frac{kr}{2} E_0 sin(kz) sin(\omega t + \phi_0)$$

$$B_\phi = \frac{kr}{2c} E_0 cos(kz) cos(\omega t + \phi_0)$$

from kz = 0 up to kz = Nπ, with N number of cells, $\omega = 2\pi\nu_{rf}$, k = $\frac{\omega}{c}$ and E_0 the peak field.

2.1 Case A : High charge bunch at moderate accelerating gradient

The active length of the accelerating RF field is taken to be N=1/2+10 cells, with an accelerating gradient of $E_0 = 40$ MV/m at ν_{rf} = 1.3 GHz. This high charge case simulates a cigar-like bunch with space charge emittance compensation.

Case A no magnetic field

Q = 5 nC	E_0 = 40 MV/m	ν_{rf} = 1.3 GHz
σ_r = 2 mm	σ_t = 8.33 ps	ϕ_0 = 53 degrees

Case A$^{'}$ - case A with magnetic field

Q = 5 nC	E_0 = 40 MV/m	ν_{rf} = 1.3 GHz
σ_r = 2 mm	σ_t = 8.33 ps	ϕ_0 = 53 degrees

External solenoid magnetic field specifications :

$B_z = B_0 sin(kz)$
$B_r = -\frac{kr}{2} cos(kz)$ from kz = 0 up to kz = $\frac{\pi}{2}$

$B_z = B_0$
$B_r = 0$ from kz = $\frac{\pi}{2}$ up to kz = (4+$\frac{1}{2}$)π

$B_z = B_0 \frac{(1-cos(2kz))}{2}$
$B_r = -\frac{kr}{2} B_0 sin(2kz)$ from kz = (4+$\frac{1}{2}$)π up kz = 5π
with B_0 = 1 kGauss.

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2.2 *Case B : Low charge bunch at high accelerating gradient*

This low charge case studies a disk-like short bunch.

Case B with N = $\frac{1}{2}$ + 2

Q = 1 nC	E_0 = 100 MV/m	ν_{rf} = 2.856 GHz
σ_r = 3 mm	σ_t = 2 ps	ϕ_0 = 60 degrees

Case B$'$ case B with N = $\frac{1}{2}$ + 10

Q = 4 nC	E_0 = 100 MV/m	ν_{rf} = 2.856 GHz
σ_r = 3 mm	σ_t = 2 ps	ϕ_0 = 60 degrees

3 TYPICAL OUTPUTS

We choose to compare the 3 codes by plotting some parameters along acceleration as a function of the average bunch position $< z >$ (mm). The parameters are rms beam radius $\sqrt{< r^2 >}$ (mm), rms bunch length $\sqrt{< \Delta z^2 >}$, energy $< W >$ (MeV), energy spread $\frac{\sqrt{<\Delta\gamma^2>}}{<\gamma>}$, normalized transverse rms emittance ϵ_n (whole bunch, i.e. computed over all particles, in mm-mrad), full bunch length L and maximum radius R (mm). To ouput results we use a standard ASCII file with the following structure in free format : $< z >$, $\sqrt{< r^2 >}$, $\sqrt{< \Delta z^2 >}$, $< W >$, $\frac{\sqrt{<\Delta\gamma^2>}}{<\gamma>}$, ϵ_n, L, R

4 COMMENTS ON RESULTS

Although we observe a difference close to 5 or 10 $\%$ on the values, the figure shown the same position for minimum and maximum. We can assume that there is a good agreement for the dynamic calculation in the external RF fields. We can explain the disagreement between the curves (see fig.1 and fig.2) by :

- First, for the bunch we known that for a gaussian the initial rms beam radius is $\sqrt{2}\sigma_r$ in mm, if we truncate at 3σ but in each code we have a different initial beam radius (mm) which can explain the difference between the 3 codes.

	case A	case B
theoritical	2.828	4.242
ATRAP	2.755	4.133
ITACA	2.526	3.795
PARMELA	2.799	4.265

For ITACA it seems that we have to take the value for the rms radius at the position in z where the bunch is completely emitted from the cathode, for case A in z = 2.941 mm R_{rms} = 2.676 mm and for case B in z = 0.649 mm R_{rms} = 4.004 mm. The table becomes

	case A	case B
theoritical	2.828	4.242
ATRAP	2.755	4.133
ITACA	2.676	4.004
PARMELA	2.799	4.265

A good agreement on the position of the maxima and minima of the oscillations in the transverse emittance (see fig. 3) is obtain. Applying the same normalization as for rms radius one obtain much better agreement in the exit value of the normalized values of emittance.

	case A	case B
ATRAP	4.42	0.53
ITACA	5.20	0.57
PARMELA	4.86	0.62

- Second, we known a good approximation for the full bunch length after acceleration L = 6 c σ_t with c the light velocity (at optimum injection phase, giving maximum acceleration), see figure 4.

	case A	case B
theoritical	14.99	3.60
ATRAP	15.97	3.58
ITACA	15.07	4.40
PARMELA	14.12	3.34

An other point is the CPU time by example for case A without magnetic field ATRAP on an HP workstation 9000/735 use 45 minutes with 3000 particles, ITACA on an AlphaStation 200 use 2 hours with 1800 particles and PARMELA on the same Alpha machine use 3 hours for 1000 particles.

For simulations of very small bunches (both in length and transverse sizes) and long acceleration section the CPU time scaling is much more favorable for particule-pushing code like ATRAP and PARMELA than P.I.C. like ITACA.

5 REFERENCES

[1] J.L. Coacolo, Doctorate dissertation, Université Joseph Fourier Grenoble I (1993)

[2] L. Serafini and C. Pagani, ITACA : A new computer code for the integration of transient particle and field equations in axi-symmetrical cavities, Proc. 1st EPAC, Rome June 1988, p.866-868

[3] B. Mouton, The PARMELA Program, Version 5.00 of Orsay Implementation

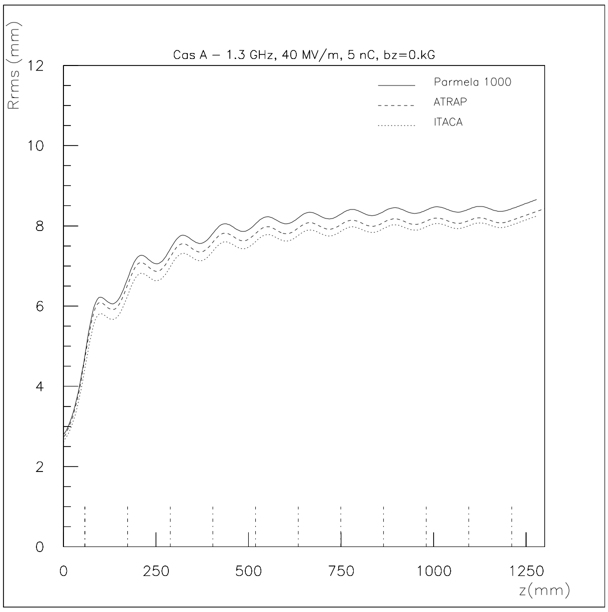

Figure 1 : Case A without magnetic field

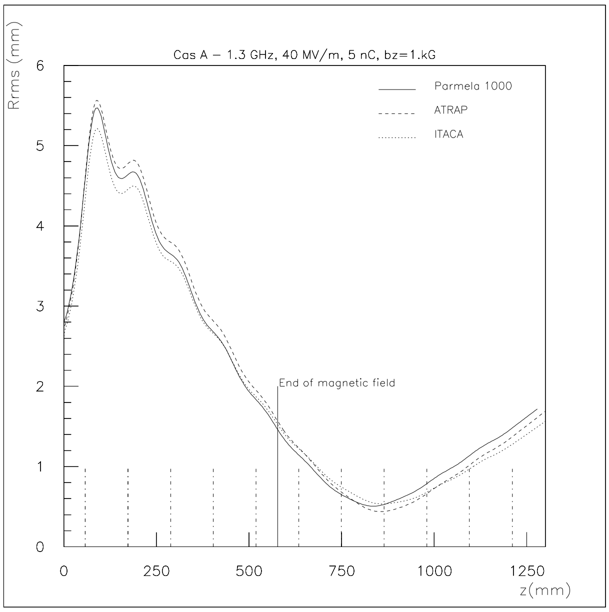

Figure 2 : Case A with magnetic field

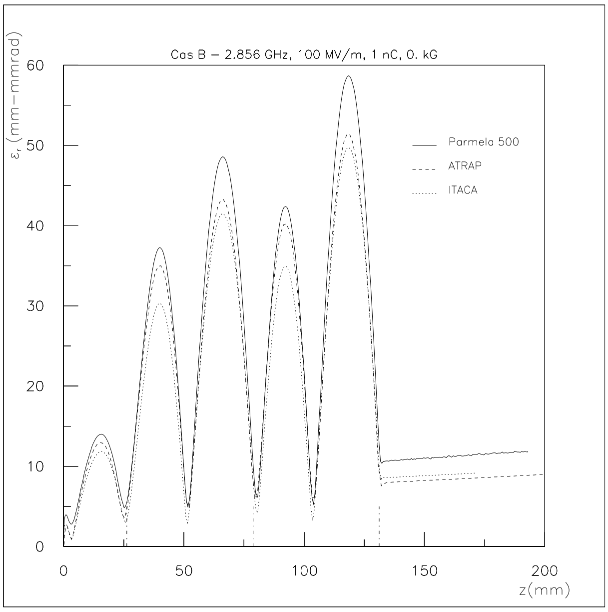

Figure 3 : Case B with N = $\frac{1}{2}$ *+ 2*

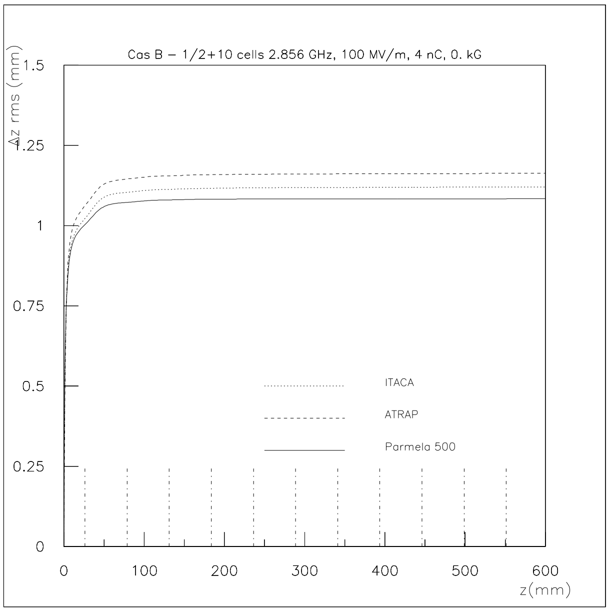

Figure 4 : Case B with N = $\frac{1}{2}$ *+ 10*