UCRL--92876

DE86 002135

IFR CODE FOR SECONDARY PARTICLE DYNAMICS

M. R. Teague and S. S. Yu

This paper was prepared for submittal to
the Annual Propagation Review, Naval
Postgraduate School, Monterey, CA
June 24-28, 1985

October 11, 1985

Lawrence Livermore National Laboratory

DISCLAIMER

IFR CODE FOR SECONDARY PARTICLE DYNAMICS*

M. R. Teague and S. S. Yu
Lawrence Livermore National Laboratory
P.O. Box 808
Livermore, California 94550

October 11, 1985

ABSTRACT

A numerical simulation has been constructed to obtain a detailed, quantitative estimate of the electromagnetic fields and currents existing in the Advanced Test Accelerator under conditions of laser guiding. The code treats the secondary electrons by particle simulation and the beam dynamics by a time-dependent envelope model. The simulation gives a fully relativistic description of secondary electrons moving in selfconsistent electromagnetic fields. The calculations are made using coordinates t, x, y, z for the electrons and t, ct-z, r for the axisymmetric electromagnetic fields and currents. Code results, showing in particular current enhancement effects, will be given.

* Work performed jointly under the auspices of the U. S. Department of Energy by Lawrence Livermore National Laboratory under contract W-7405-ENG-48 and for the Department of Defense under Defense Advanced Research Projects Agency ARPA Order No. 4395, monitored by Naval Surface Weapons Center under document number N60921-85-POW0001, and Naval Surface Weapons Center under document number N60921-85-WRW0201. Subject to Export Control Laws.

I. CALCULATION OF ELECTROMAGNETIC FIELDS AND SECONDARY PARTICLE MOTION

We consider the time evolution of a system consisting of beam associated electromagnetic fields E and B satisfying Maxwell's equations

$$\frac{1}{c}\frac{\partial \vec{E}}{\partial t} = \nabla \times \vec{B} - \frac{4\pi}{c}\vec{J} \quad (1)$$

$$\frac{1}{c}\frac{\partial \vec{B}}{\partial t} = -\nabla \times \vec{E} \quad (2)$$

and N secondary electrons with positions $\vec{r}_j$ and velocities $\vec{v}_j$ satisfying the relativistic equations of motion (j=1,N)

$$\frac{d}{dt}\frac{\vec{v}_j}{(1-v_j^2/c^2)^{1/2}} = \frac{e}{m}[\vec{E}(r_j,t) + \frac{\vec{v}_j}{c} \times B(\vec{r}_j, t)] \quad . \quad (3)$$

(The two divergence equations $\nabla \cdot \vec{E} = 4\pi\rho$ and $\nabla \cdot \vec{B} = 0$ are imposed as initial conditions.) The current $\vec{J}$ in Eq. (2) has contributions from secondary and beam electrons and ions.

Suppose the beam propagates in the +z direction. If the currents and boundary conditions are axisymmetric, then all field quantities depend only on $r = (x^2 + y^2)^{1/2}$, z, and t. However, it is convenient to use as independent variables r, ζ, and t, where

$$\zeta = ct - z \quad (4)$$

is the (positive) distance behind the beam front. In the axisymmetric case a closed set of equations may be obtained for the three field components E_r, E_z, B_θ and the two current components J_r and J_z. For beam particles with axial velocities essentially equal to c, $\partial/\partial t << c\ \partial/\partial\zeta$ for any field quantity. In the limit that $\partial/\partial t$ terms are negligibly small, Maxwell's equations become

$$\frac{\partial}{\partial r} E_z = \frac{4\pi}{c} J_r \tag{5}$$

$$\frac{\partial}{\partial \zeta} (E_r - B_\theta) = - \frac{4\pi}{c} J_r \tag{6}$$

$$\frac{1}{r} \frac{\partial}{\partial r} r B_\theta = \frac{4\pi}{c} J_z + \frac{\partial}{\partial \zeta} E_z \quad . \tag{7}$$

All fields and currents in Eqs. (5-7) are functions of r, ζ, t. However, t is no longer an independent variable in the field equations but rather a parameter: the fields at time t are produced solely by the currents at time t. Time is, of course, the appropriate independent variable for secondary particle motion. As the particles move the associated currents are generally time-dependent, which injects a parametric time-dependence into the fields via Eqs. (5-7). (Any external accelerating and focusing fields affect the secondary electron motion through Eq. (3), but the external fields are not included in Eqs. (5-7).)

Since the ions are nonrelativistic and respond essentially only to E_r it is inappropriate to treat the ion motion with the relativistic equation of motion Eq. (3) and the complete Maxwell's equations Eqs. (1-2) . Accordingly ions are treated by the non-relativistic equation of motion

$$\frac{d}{dt} \vec{r}_j = \frac{q_{ion}}{m_{ion}} \vec{E}_r(\vec{r}_j) \quad , \tag{8}$$

where E_r is calculated from the ion and electron charge densities ρ_i and ρ_e using Poisson's equation

$$\frac{1}{r}\frac{\partial}{\partial r} r E_r = 4\pi [\rho_i + \rho_e] \quad . \tag{9}$$

II. SIMULATION DETAILS

The field equations (5-7) are solved on an $r - \zeta$ grid. To obtain a fully centered differencing scheme for Eqs. (5-7), four separate interlaced grids are used, and non-linear gridding in r is used to increase the number of points near the beam axis. Appropriate boundary conditions on the fields are specified on the beam axis, beam wall, and beam head. The two-dimensional array is protected on all four sides by guard cells so that physical particles always lie in interior cells of the field array and never on edge cells. A completely relativistic particle push [4] valid for arbitrary electric and magnetic fields is used.

III. THE BENZENE CONDITIONING CELL

After propagating through all the ATA accelerating modules the laser-guided electron beam can be quite large in its transverse dimension due to diffraction spreading of the excimer guide laser. Thus, to condition the beam before it enters the gas cell, it and the laser beam are first passed through a moderate pressure (1-10 μ) benzene cell of length 4.5 m and radius 6.7 cm. The entrance to the benzene cell is an aperture of diameter 5 mm.

Thus, the conditioning cell is an attempt to create a wire-like guide region to focus the electron beam, establish its direction and also to damp transverse oscillations.

IV. SIMULATION RESULTS

Figure 1 shows the axial fields in the conditioning cell. Figure 2 gives the secondary electron current while Fig. 3 shows the energy distribution of the secondaries. Finally, Fig. 4 shows the particle dynamics of the electrons: the first simply is blown away and hits the wall; while the second is carried along with the beam.

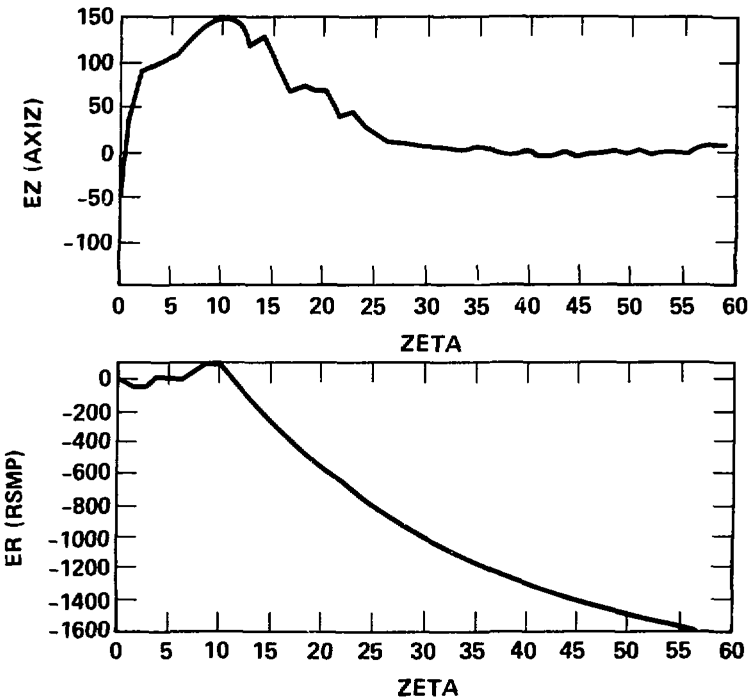
150
100
50
0
-50
-100
EZ (AXIZ)
0 5 10 15 20 25 30 35 40 45 50 55 60
ZETA
0
-200
-400
-600
-800
-1000
-1200
-1400
-1600
ER (RSMP)
0 5 10 15 20 25 30 35 40 45 50 55 60
ZETA

Figure 1

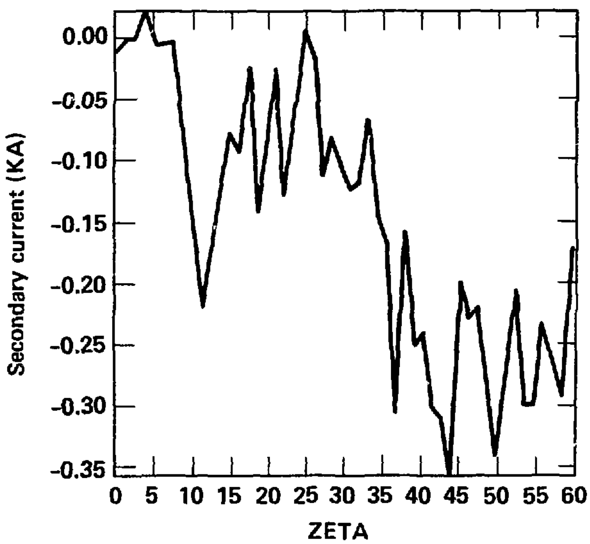
Secondary current (KA)
0.00
-0.05
-0.10
-0.15
-0.20
-0.25
-0.30
-0.35
0 5 10 15 20 25 30 35 40 45 50 55 60
ZETA

Figure 2

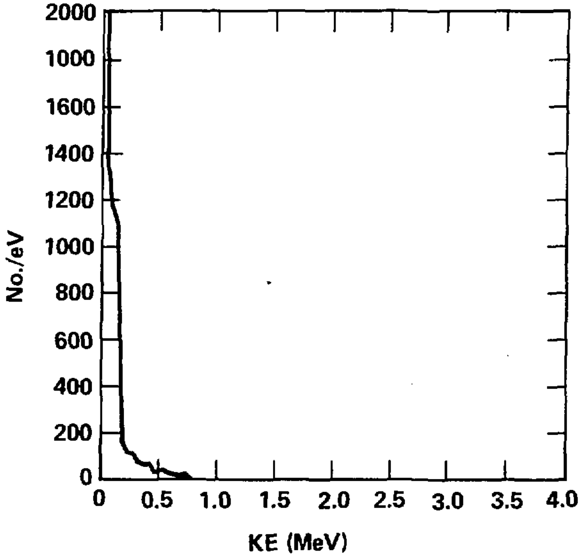
2000
1000
1600
1400
1200
1000
800
600
400
200
0
No./eV
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
KE (MeV)

Figure 3

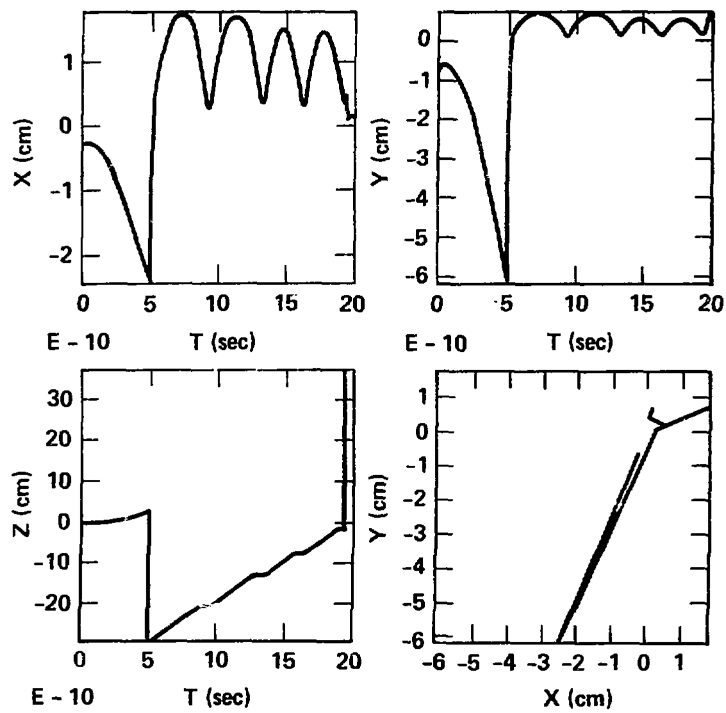

Figure 4

REFERENCES

[1] M. R. Teague and S. S. Yu, "Numerical Simulation of Secondary Orbits Near an Electron Beam Propagating in a Low Pressure Gas," 1985 Particle Accelerator Conference, paper E23, May 1985.

[2] W. E. Martin, G. J. Caporaso, W. M. Fawley, D. Prosnitz, and A. G. Cole," Electron Beam Guiding and Phase-Mix Damping by a Laser-Ionized Channel," Phys. Rev. Lett. 54, 685-688 (1985).

[3] E. P. Lee and R. K. Cooper, "General Envelope Equations for Cylindrically Symmetric Charged-Particle Beams," Particle Accelerators 7, 83-95 (1976).

[4] C. K. Birdsall and A. B. Langdon, Plasma Physics Via Computer Simulation, Mc Graw-Hill, New York 1985. Section 15-4 describes a version (which is used in our simulation) of the relativistic particle push developed by J. Boris (1970).