TIME STEPPING KLYSTRON AND LASERTRON SIMULATIONS

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Abstract

During the last two years a 2½D computer code has been worked out at Orsay [1] to simulate the dynamics of electrons in micropulsed RF sources, such as lasertrons [2] [3] .

The goal of this new code is to take advantage of time stepping to get closer to the real case of the Orsay lasertron, and be capable to work on other RF devices (klystrons, FEL injectors ...).

OAK Code

The new code named OAK, is an updated and more powerful, extended version of the lasertron simulation program RING [1]. Ring uses time as an independent variable (time stepping) to track Z and r (longitudinal and radial positions) of electrons in a lasertron geometry (DC + RF zone).

Green functions or approximated expressions of the space charge are included, as well as static DC high voltages. Steady-state RF fields are analytically computed or included from external codes such as SUPERFISH. Self consistent iterations are performed over the RF field values to determine the gap voltage or the Qx.

The main new features specific to OAK are :

- any kind of cylindrical RF geometry can be taken into account via SUPERFISH, whereas RING is only able to work on symmetric (from their center) output cavities

- the structure is made more modular and allows, for example, the emission of electrons within the RF structure (see example below), and, as a short term goal, will provide an easy and free organization of the emission, DC and RF zones

- the electronic emission is variable in density and energy, thus specific shapes (Gaussian, trigonometric, class A-B-C...) are already included or may be introduced by the operator to follow an experimentally complicated case [4]

- the code DESSIN, which produces the graphic output has been strongly modified to provide new tools in addition to the bunch and velocity photos :

  . Animated cartoons of the bunch motion and E-field evolution are available.

  . All the Ez, Er, Bz, Br, Bφ fields, whether external or from space charge, are tracked by any chosen electron of the bunch or by two fixed points in the geometry, then plotted in direction and intensity.

  . R positions, as well as Vz, Vr, Vφ speeds and kinetic energy of the electrons are plotted versus time or z position as variables.
  In the time case, it is also possible to fix the boundary conditions diagnosis on any two chosen Z planes (position of a detector, a Faraday cup...).

  . An analytical expression of 2 D local electric fields developed in a needle area is also included. This is intended to provide an attempt of simulation for the current experiments in the Orsay lasertron [4] (see example below).

  . Fast space charge models (varying as the number n of electrons, instead of n! or n^2) are under test for low-accuracy simulations.

Motivation for Time-Stepping Simulations

In most (z,θ) simulation codes, θ is generally the phase of each electron, compared to a constant speed virtual particle ; z is increased stepwise, with r constant. This leads to approximations and mistakes that may be non-negligible important for different specific cases :

- when θ is not a continuous variable (as are z and t), therefore the expression $Vz = \frac{dz}{dt} = \frac{dz}{d\theta}\frac{d\theta}{dt}$ gives a relatively poor approximation.

- when the speed of particles is assumed to be, to first order, modulated about a constant value. This is false in devices such as lasertron, injection guns ... where the electrons are emitted with a speed nearly equal to zero

- in (z,θ) codes where all the electrons exist at the beginning of the simulation, which makes it impossible to simulate the cathode emission, especially because of the very time dependent space charge effects that happen within the bunch, and the image charges that appear on the cathode (cathode charge extraction limits ...) [3] OAK proposes as well a collective or a sequential declaration of the electrons

- as the z position of the analysis increases in (z,θ) codes, all backwards phenomena are omitted (reflected electrons, oscillations ...)

- periodic similar bunches are easily taken in account by the (z,θ) method, whereas for (z,t) one must use at least two copies of the current bunch. This may be done with a very reasonable time expense, however, as the tracked bunch still remains single. On the other hand, the (z,θ) model, based on periodic hypothesis cannot simulate the non-constant speed cases which occur when the bunch is pushed in a non-uniform field geometry.

Examples

Orsay Lasertron

Orsay lasertron emission is based upon photoemission and field-emission effects, triggered by a laser.

OAK is very recently capable of simulating a local field enhancement due to a needle.

The chosen theoretical shape of the needle is ellipsoidal. Er(r,z), Ez(r,z), and V(r,z) (see Figure 1) are given analytically.

OAK is intended to describe the space charge effects in needle emission in terms of charge extraction limit, shape of the emitted bunch, and induced space and time delay.

Knowing Qvol, defined as the maximum of charge available from the cathode during laser illumination (considering only inner effects such as diffusion speed, volume of the cathode, output speed or density shape in time), OAK allows, step by step, the electrons to leave the cathode with a given density and predicts whether the total field $E_{DC} + E_{sp.charge}$ pushes the particles in DC acceleration zones or back towards the cathode (thus $Q_{max.} < Q_{vol}$). Specific effects occur in the needle case, due to the tremendous local field values (about 1 MV/mm) which allows electrons to leave the needle if $Q < Q_{vol}$ even after reaching the space charge annulation of the non-local DC field. The charges that are emitted then stay close to the cathode, waiting for the total field to become accelerating, following the removal of previously emitted electrons. This effect may induce a long time delay and a strong explosion of the bunch tail [4].

FEL Photo Injector

OAK has been performed for simulating an FEL photo injector [5]. Studied parameters were :

- effect of cathode surface
- effect of the current
- effect of the gap voltage
- effect of the RF phases
- beam confinement
- search for maximum charge extraction
- effect of laser shape.

Figure 2 shows some photos of the bunch, and Figures 3 and 4 the effect of phases on observed kinetic energy from two fixed z positions.

Time Stepping in Klystron Simulation

One of the main interesting aspects of the use of an (r,z,t) variables code, working with a description of the real cavities coming from a code as SUPERFISH, is to establish an array of data for (Er,Ez) which can be interpolated in RF areas, consisting of a description of radial and backwards phenomena. This provides tools for understanding important experimental phenomena that have remained out of the scope of previous (z,0) simulations.

Figure 5 shows the behaviour of a bunch when passing through an output cavity, with a given Bz which happens to be too small, as some electrons collide with the metal surface with a strong energy, causing major heating effects.

Figure 6 gives Vz versus time ; two electrons are oscillating in the gap. None are reflected, as they finally collide with the material.

Figures 7 and 8 were obtained with smaller interaction and stronger Bz.

The problem appears to be solved, but for a lower efficiency.

OAK evolution in the area of klystron simulations is still going on. The aim is to have a totally modular program that will make it easy to simulate klystrons, lasertron, RF guns ... as well as linear accelerator segments.

Aknowledgments

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References

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[2] A. Dubrovin and J.P. Coulon, "Simulations des performances du lasertron", LAL-RT-87-07, May 1987, Orsay France.

[3] A. Dubrovin and J.P. Coulon, "Laser Computer Simulations at Orsay" : "RING Code" Proceedings ECFA 87-110 CERN 87-11, p. 259.

[4] A. Dubrovin, "Premières simulations de la photo-émission de champ dans le lasertron par OAK", to be published-LAL-Orsay France.

[5] R. Dei-Cas, "A High Brightness Photo Injector for FEL", Contribution to these Proceedings-CEA, Bruyères-le-Chatel France.

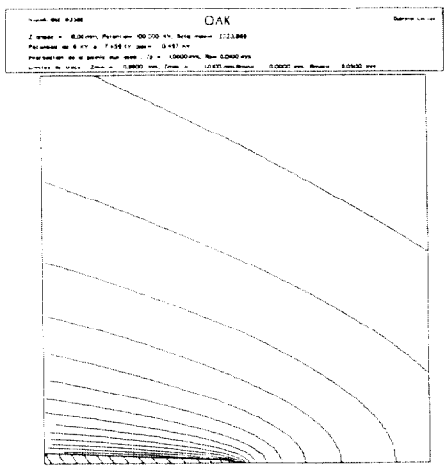

Figure 1 - OAK : Equipotentials in the region around an ellipsoidal needle

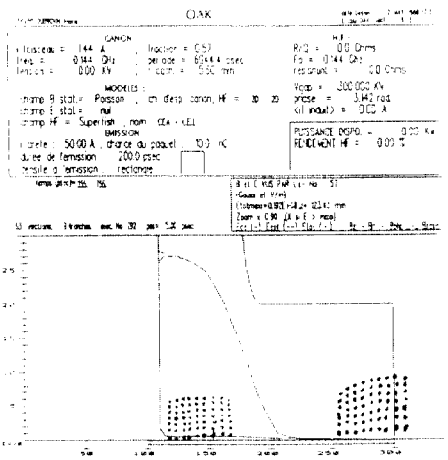

Figure 2 - FEL injector simulation : bunch behaviour

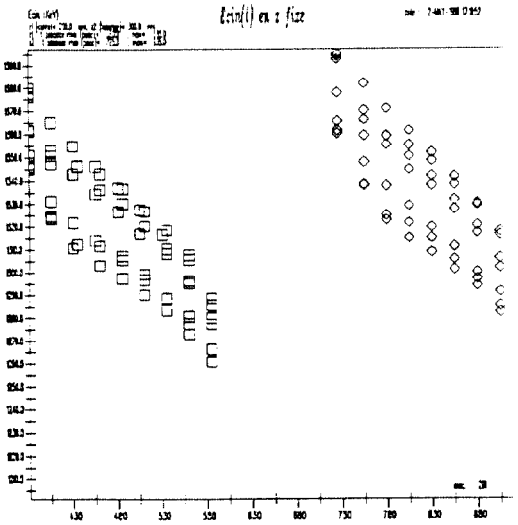

Figure 3 - Effect on phases : bad choice

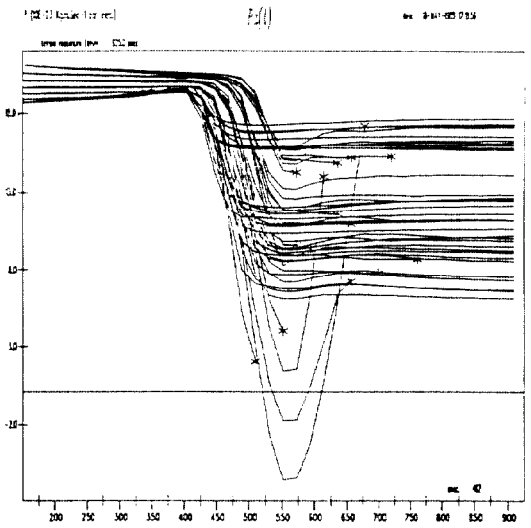

Figure 6 - $Pz(t) = \gamma(t)\, m_o\, v_z(t)$, Bad Bz

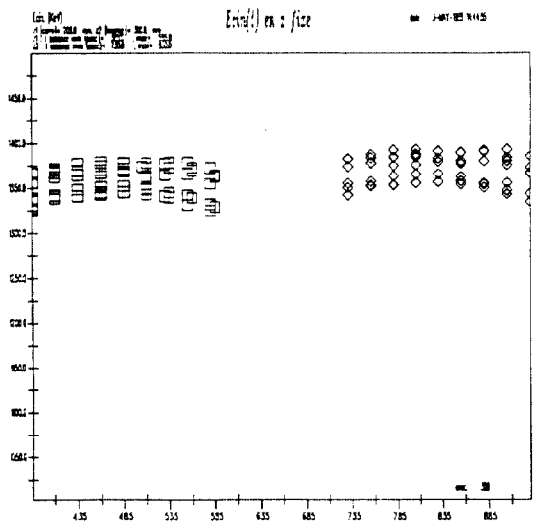

Figure 4 - Effect on phases : good choice

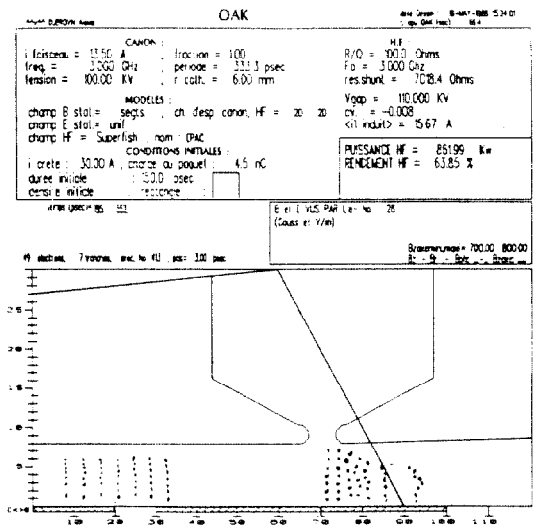

Figure 7 - Good Bz

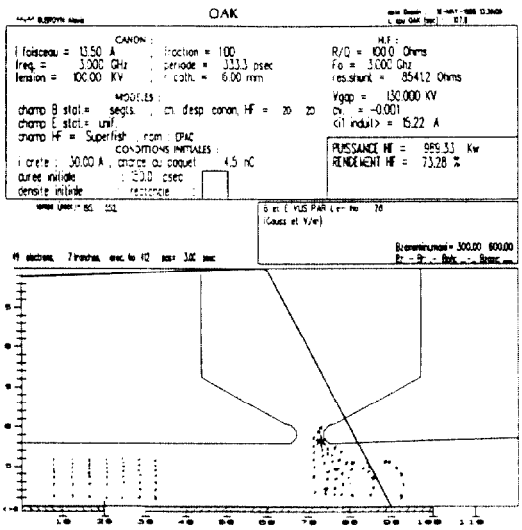

Figure 5 - Bunch motions in an output cavity - Bad Bz

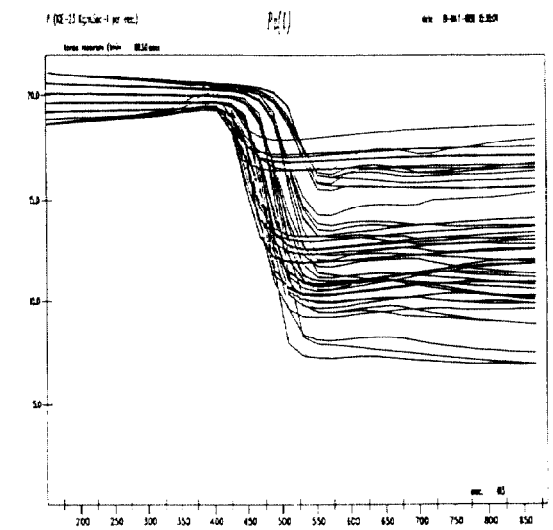

Figure 8 - Pz(t), good Bz