DESIGN OF A HIGH INTENSITY ELECTRON BUNCHER

D. Tronc, C. Bourat, J.P. Georges and A. Setty
Thomson-CGR MeV, BP 34, 78530 Buc, France
B. Spataro
L.N.I., Via E. Fermi 40, 00044 Frascati, Italy

Introduction

A 2856 MHz high intensity electron injector derived from the CERN-LIL front end[1] will be put in december 1986 at the beginning of the Frascati e+ e- linac (see companion paper[2] and [3]). After a general description we analyze the longitudinal dynamics at the beginning of the buncher where a new geometry increases the electron capture. We present simulation results taking account of the radial dynamics and of the space-charge effects. Comparison is made between an ellipsoidal space-charge model, the ESPEL code and a modified version of the PARMELA code. This injector is the prototype of a moderate cost unit designed to accelerate up to 100 nano Coulomb without constraints on adjustments of sensitive parameters.

General description

Figure 1 shows the geometry of the injector. It is a cut-away view of the components along the beam line. The triode gun[1] can deliver up to 20 A for 10 ns pulses. The beam diameter at the crossover is estimated to be equal to 7 mm. It is known that the main cause for poor emittance is due to the grid bars spacing, when it becomes comparable to the grid-cathode distance. This introduces equipotential distorsions as the grid potential does not respect the diode equipotential value when short intense electronic pulses are extracted from the cathode. Then crossing of the electronic trajectories occurs. This is avoided by the use of a new grid of .05 mm tungsten wires spaced by .5 mm. The correct spherical shape depends on a secondary "grid" of larger bars which acts as a mechanical support.

The buncher is a biperiodic standing-wave E-coupled structure of 1.1 meter length. The design point has been set at 7.5 MW RF power and provision has been made to work at any level between 6 MW and 10 MW.

The focusing uses a nearly uniform solenoïdal field of .12 T to .15 T, reaching full amplitude in less than one centimeter at the exit of the gun anode, slightly before the expected beam crossover. Due to this large focussing there is an inner scalloping. It would be interesting to have a minimum at the input of the first RF cell to reduce the adverse effects of the radial RF components[4]. But the distance between the crossover and the first cell is large because a valve is needed at this point and trajectories become mixed, blurring the minimum.

Longitudinal dynamics

The measurements made on the LIL injector have shown that an unexpectably high percentage of the available electrons were accelerated when the bunching/accelerating cell was overfed[5]. The analysis of the dynamics explained how phase bunching following closely energy modulation inside the cell itself led to this good capture [4, 5, 6]. Even longitudinally oscillating electrons are finally trapped forwardly under a given maximum field level [7].

This led us to define a new geometry which associates this first cell to the periodic buncher structure [8]. This simplifies the geometry and the adjustment of parameters. Figure 2 is a section of the first three active cells together with the accelerating field law. It corresponds to the critical part where electrons energies are lower than 2 MeV. The first cell is undercoupled at the π mode to the cell which begins the biperiodic structure (we avoid a short empty cell between the two active cells to reduce the on-axis drift and the number of parameters).

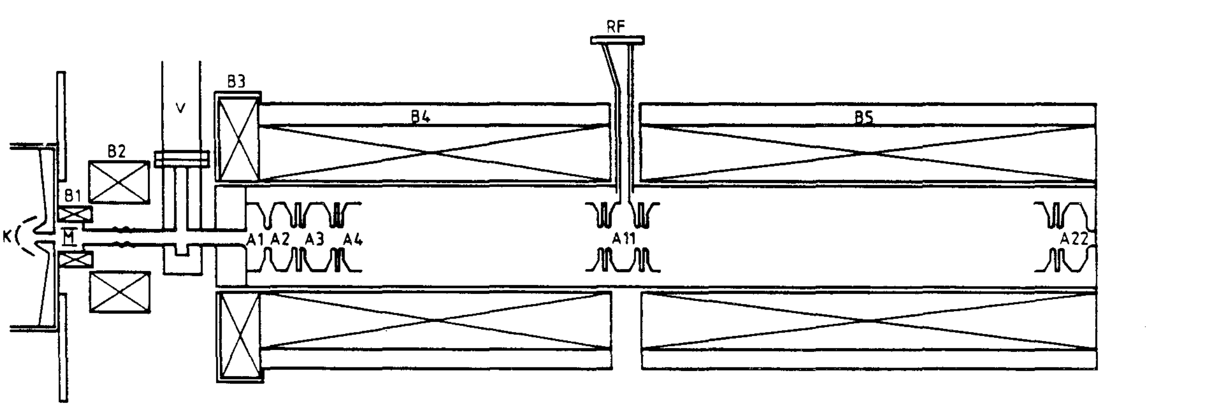


Fig. 1 : Frascati electron injector. K gun cathode, M monitor, B sonenoids, A accelerating cells, V vacuum valve.

Then ideally :

1. Electron capture and energy modulation occur in the first cell which acts as a longitudinal trapping device for nearly all the input electrons. This occurs at a moderate field level where the electrons cross the equivalent "potential wall" in the forward direction only.
2. Phase bunching and acceleration occur in the second cell at a higher field level. This limits the space charge and the beam loading adverse effects.

In the present FRASCATI design the capture process is not optimized. The field level is too high in the first cell reaching 16 MV/m (for an optimum value around 10 MV/m) as we limited at 2:1 the ratio of the field maximum in cell 2 (and following ones) to the field maximum in cell 1.

Figure 3 presents the dynamics between the first cell input and the second cell mid-plane. Figure 3a presents the energies vs z-axis : a large spread occurs. If the field in the cell is not too large all electrons cross it. However here one "electron"a is stopped in the second half of the first cell. Figure 3b presents the corresponding phases to show how bunching occurs in a very short length following closely the energy modulation.

In figure 4 the capture ratio and the beam accelerated charge for an energy spread due to loading are represented vs RF power. The charge is given in nC. RF power of 7.5 MW corresponds to the Frascati design point.

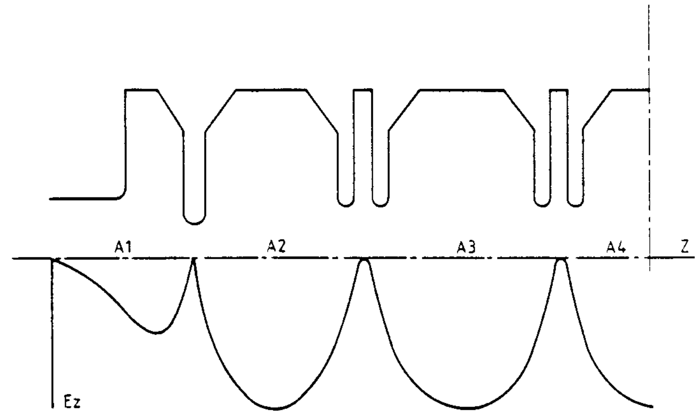
The isolated point corresponds to the capture which would occur with a conventional design (without first cell at lower field). The goal of delivering more than 5A on the e-e+ conversion target for short pulses is easily reached. At moderate accelerated charge RF power could be reduced to a few MW.

<u>Radial dynamics with space-charge effects</u>

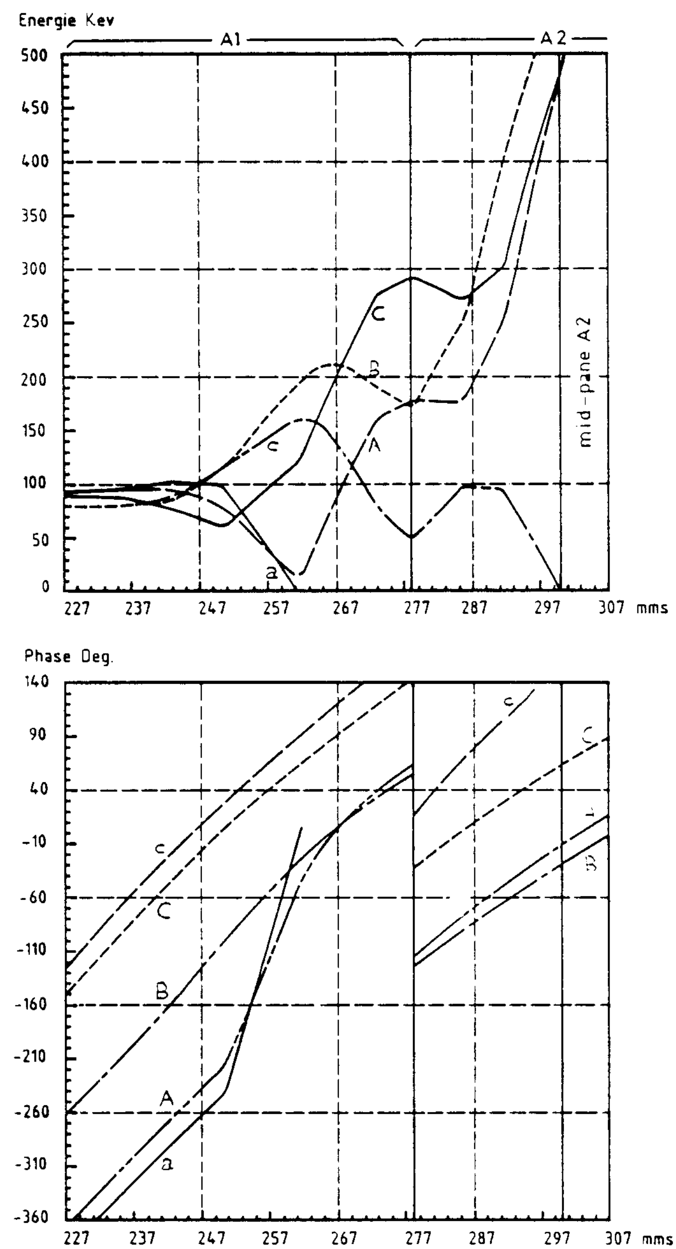
We compare simulations including the effects of preexistent radial as well as beam space-charge fields. They include the ELLIPSE code based on an ellipsoidal distribution, the ESPEL code used at Thomson CGR, the well-known PARMELA code modified.
The ellipsoïdal model permits only the analysis of already formed bunches but is simple and the corresponding code is fast. ESPEL and PARMELA are based on the study of "macroparticles" dynamics and space charge evaluation in meshes. They are well adapted to a detailed study but are quite slow. In the simulations the initial 20A beam has a 90 keV energy and is accelerated by the structure at his nominal point of 7.5 MW (that is a 32 MV/m peak field and 16 MV/m in the first cell). It is focused by 1300 G solenoidal magnetic field. The emittance is estimated to be 30 π mmrad.

The PARMELA program has been used with some modifications[9], in particular :

1. The RF fields take into account the dissymetry of the first cell.



<u>Fig. 2</u> : Buncher first cells and accelerating field.



<u>Fig. 3</u> : Energies (a) and phase (b) of five characteristics "electrons" from the input to the second cell mid-plane. A,B,C, accelerated a,c lost.

2. The space charge subroutine is modified to establish fields created by particles in the moving frame. It makes relativistic corrections for energy modulations and give a new formulation of the space charge impulses.

A detailed study of beam behaviour in the first cells [10] is illustrated by Figure 5 which shows "instantaneous photographs" of the bunch along the z-axis. The strong energy modulation which occurs in the first cell, stops some electrons. The configuration of the beam is virtually established at the second cell mid-plane. Finally, some electrons are progressively lost, and the structure accelerates about 65 % of electrons. 10 A or 50 % of the initial charge are bunched in about 30 degrees of phase.

The ellipsoidal model is based on the study of four characteristics points : the maximum radius point, the two extremities of the bunch, and the center. For an ellipsoid of R radius and 2L length, moving with velocity β we calculate the space charge field in the laboratory frame as :

$$E_r = \frac{-3Q}{8\pi\varepsilon_o RL}\left[1 - \frac{R^2}{\gamma^2 L^2}\sum\right]$$

$$E_z = \frac{-3Q}{4\pi\varepsilon_o \gamma^2 L^2}\sum$$

where $\gamma = \frac{1}{\sqrt{1-\beta^2}}$ and

$$\sum = \begin{cases} \frac{1}{e_1^3}\left[e_1 - \operatorname{arctg} e_1\right] ; \; e_1 = \frac{1}{\gamma L}\sqrt{R^2 - \gamma^2 L^2} \text{ if } \gamma L < R \\ \frac{1}{e_2^3}\left[\ell n\sqrt{\frac{1+e_2}{1-e_2}} - e_2\right] ; \; e_2 = \frac{1}{\gamma L}\sqrt{\gamma^2 L^2 - R^2} \text{ if } \gamma L > R \\ \frac{1}{3} \text{ if } \gamma L = R \end{cases}$$

The problem leads to solve eight first order differential equations by a Runge-Kutta method, which characterize the radial, longitudinal and energetic behaviour of the bunch [3, 10]. We consider an initial ellipsoidal bunch at a point of structure where the beam has nearly reached its final configuration.

Figure 6 shows the beam radius vs z-axis. For PARMELA and ESPEL codes, the beam radius is estimated as two times the standard deviation, that is 95 % of electrons for a Gaussian distribution. For ELLIPSE, the beam envelope is given. It is characterized by two maxima, in the first and third cells, due to strong space charge forces below 2 MeV. Then the radius decreases. The ripples are due to the alternated effects of focusing and defocusing RF fields. The three different approaches are in good agreement.

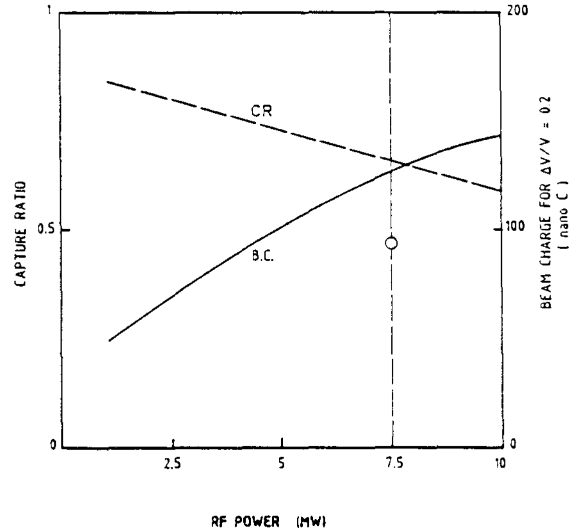


Fig. 4 : Capture ratio and accelerated beam charge for V/ΔV = 0.2 vs RF power.

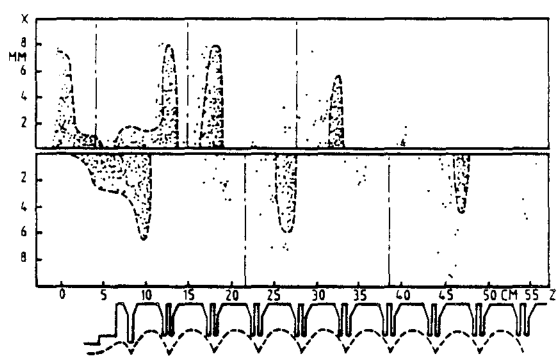


Fig. 5 : Transverse coordinate X versus z-axis (PARMELA code).

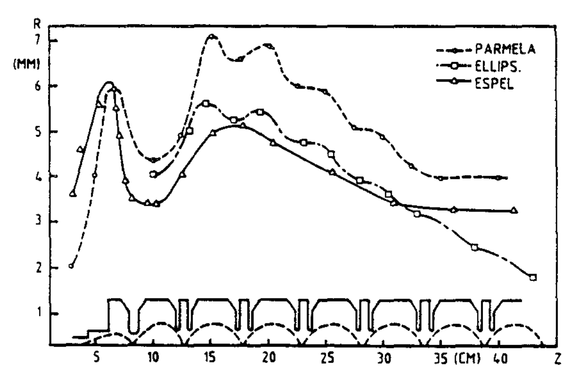


Fig. 6 : Bunch radius versus z-axis.

References

1. P. Brunet, R. Chaput, LIL front end description and experimental results, Proc. of the 1984 Linear Acc. Conf., 189.
2. F. Tazzioli and al., Field computations and measurements on a biperiodic buncher structure, 1986, this conference.
3. D. Tronc and al., Frascati high intensity electrons injection study, Thomson CGR MeV report DT 10076, 1985
4. D.Tronc and al., Electron injector designs..., 1985 Particle Acc. Conf., IEEE NS 32, 3246.
5. R.Belbeoch, Longueur des paquets d'electrons..., LAL PI 85-18/T, 1985
6. R. Chaput, Fonctionnement de la cavité de prégroupement CGR MeV à fort champ, LAL PI 85-20/T, 1985
7. S. Kulinski, large signal electron bunching, PS/LPI/note 85.11, 1985.
8. D. Tronc, French patent 85 13416
9. C. Bourat, Contribution à l'étude du programme PARMELA, DPH-N/Saclay report n°2293, 1985.
10. C. Bourat, Dynamique dans l'injecteur de Frascati par les codes PARMELA, ESPEL, ELLIPSE, Thomson CGR MeV report DT 11264, 1986.