A SCHEME FOR A FULLY SUPERCONDUCTING ELECTRON INJECTOR

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Introduction

We have studied a scheme of a fully superconducting electron injector, i.e. which does not use a room temperature section (as does CEBAF [1]) and that could be used for a superconducting linac.

We have supposed the avaibility of 5-cell 1.5 GHz cavities as described in [2]. The difficulty to make such a cavity capture electrons arises from the far extending fringing field (fig. 1) due to its large apertures that decelerates the incoming electrons.

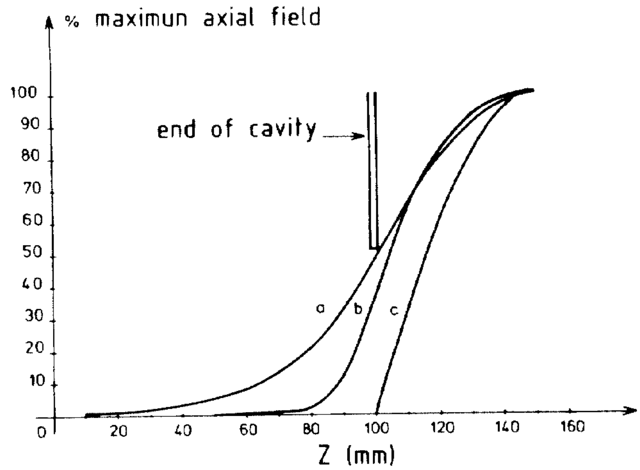

Fig. 1 - Fringing field of 1.5 GHz cells for different aperture diameter a) ϕ = 40 mm, b) ϕ = 20 mm, c) ϕ = 0.

A possible solution would be to use a very high voltage gun. This has been done at Darmstadt [3] with a 250 kV gun and 3 GHz cavities.

With a 1.5 GHz cavity, the theory predicts a still better capture [7]. Simulations show effectively that with a 170kV gun and 7 MV/m accelerating field, one could obtain the required bunches. However this would result in a more complicated gun system than with a more usual low emittance 100kV gun. The complication is even more important for a possible polarized electron source.

We propose using a single cell S.C. cavity for preacceleration followed by 2 "standard" 5-cell cavities for capture and acceleration (fig. 2). The fabrication of a single cell cavity does not require a special study as it is a necessary step in the design of the 5-cell cavities. Only a different cryostat will have to be built.

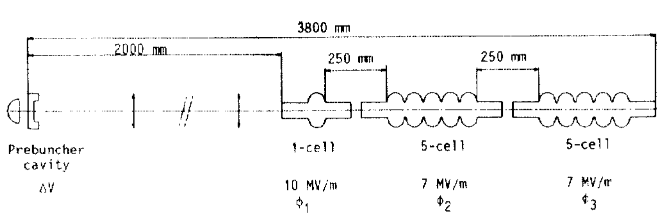

Fig. 2 - Schematic of the proposed electron injector. Initial bunch : 100kV, $\Delta E=0$, $\Delta\phi=60°$, $\epsilon=1\pi$ mm.mrad.

Short description of the injector elements

Electron gun

Several laboratories have described their using a low emittance, low current, CW electron gun built by the same manufacturer [4,5]. Emittance ranges from 1 to 5π mm.rad. Commercial avaibility of such guns and the the wide experience of their utilization are good reasons for keeping 100 kV as gun voltage.

Chopper-prebuncher

The same laboratories report also on such assemblies without gun emittance deterioration. In our case, the chopping angle would be 60 °, i.e. a transmitted current 1/6th the gun current. For a 100 µA linac average current a 1 mA maximum current gun is suitable. The drift space following the prebunching cavity has been chosen 2 m long in order to lower the velocity modulation.

Superconductiong cavities

Cells have a spherical shape. The iris diameter for the 5-cell cavities is 70 mm for internal ones and 80 mm for outer ones. These values are necessary for a good transmission of the H.O.M.. For a single cell, this constraint does not exist. So the fringing field can be reduced in taking 40 mm apertures. Accelerating fiels have been taken equal to 7 MV/m for the 5-cell and 10 MV/m for the single one. These are considered as high but quite accessible values with the present state of art [6]. The distance between adjacent cavities has been taken equal to 250 mm.

Computer codes

We have used "GRHF", a locally written computer code that tracks electrons individually and therefore cannot deal with space charge forces. RF and magnetic forces are described at first order [7]. As the radial dimensions of the beam are small with respect to those of the cavities, this approximation is quite sufficient.

With standing wave and in a dimensionless form, equations are :

$$\frac{d\gamma}{dz} = -\alpha(z).\sin\phi \qquad \text{with } \alpha(z) = \frac{E(z)\lambda}{E_0}$$

$$\frac{d\phi}{dz} = -2\pi\,.\,\frac{1}{\beta} \qquad \text{with} \quad \beta = (1-\gamma^{-2})^{-1}, \qquad \frac{dr}{dz} = \frac{p_r}{\beta\gamma}$$

$$\frac{dp_r}{dz} = -\pi.\alpha(z).r.\cos\phi + \frac{r}{2\beta}.\frac{d\alpha(z)}{dz}\sin\phi - \left(\frac{c\lambda B(z)}{2E_0}\right)^2\frac{r}{\gamma\beta}$$

$$\text{where } z = \frac{Z}{\lambda},\ r = \frac{R}{\lambda},\ p_r = \frac{P_r}{m_0 c},\ E_0 = \frac{m_0 c^2}{e}$$

Z is the distance along the axis, R, the distance from the axis, P_r the transverse momentum. B(z) is the axial external focusing magnetic field. Undefined parameters have the usual significance.

In the outer cells and in the single cell, the axial electric field variation E(z) has been determined by URMEL [8]. Then we use a Fourier transform to represent it. For the internal cells, we have used a pure sine wave representation.

Once the different parameters have been optimized with GRHF, we use PARMELA [9] to evaluate space charge effects. We have modified it to include the same RF field representation.

Results of simulations

Longitudinal motion

RF phase ϕ_2 and ϕ_3 (fig. 2) are first determined to maximize the final energy. Then the prebuncher modulation ΔV and the input phase ϕ_1 in the single cell are optimized to get the best final bunching. Results are shown on figures 3 and 4 and summarized in table 1.

Table 1

Element end.	Origin at prebuncher z (mm)	E (MeV)	Energy modulation δE (keV)	Phase modulation δφ (deg)
Prebunching drift	2000	0.1	2	11.7
Single cavity	2300	0.83	11	0.9
5-cell cavity 1	3050	4.14	12	0.5
5-cell cavity 2	3800	7.57	12	0.4

Starting with a 60° phase extension, we obtain a 0.4 °× 12 keV total longitudinal phase space. This is better than the 1.5°× 30 keV typically required for producing $\Delta E/E = 10^{-4}$ at the output of a 0.5 GeV linac. It is to be noted that 100 keV initial electrons are first decelerated in the first cell down to 57 keV.

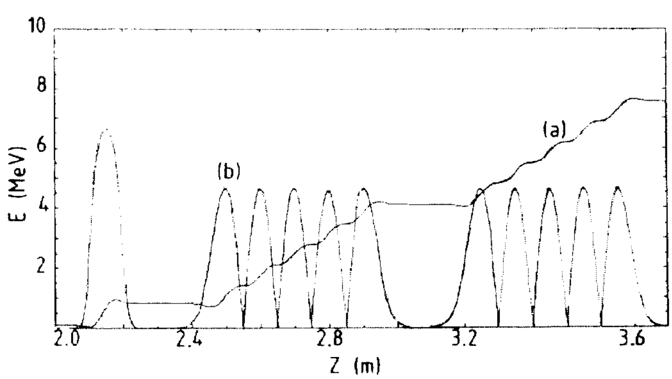

Fig. 3 - (a) Energy gain of the central electron ; (b) maximum accelerating field.

One has also to take into account the expected instability of the different parameters. Simulations show that effects of relative variations of ± 10^{-3} on RF field amplitudes and of 10^{-4} on the gun high voltage are negligible with respect to ± 0.5° variations on RF phases. The most sensitive RF phase is that of the second 5-cell cavity (fig. 4). However the total output phase variation remains inside a 1.5° window and the energy variation is negligible.

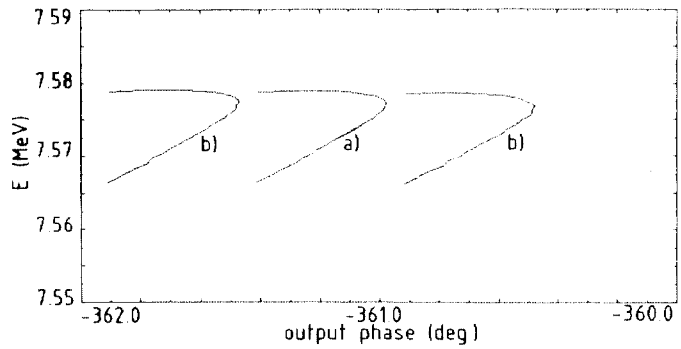

Fig. 4 - (a) Final energy phase plot for a 60 ° initial bunch ; (b) Same curves for ± 0.5 ° variation of the second 5-cell cavity RF phase.

Transverse motion

The gun emittance has been taken the smaller in the calculations (1π mm-mrd) in order to maximize possible space charge effects. The initial beam radius has been taken equal to 0.5 mm. In the 2 m prebuncher drift space, focusing is insured by two magnetic lenses represented in the computer code by a Gaussian law. This scheme is only convenient for simulations. Practically more lenses or differently spaced could be used. The radial focusing inside the cells is insured by RF forces.

Figure 5 shows different trajectories starting from the prebuncher cavity abscissa, for extreme radius, angles and phases. At this location, we have supposed an erected emittance ellipse. This gives a rough idea of the beam enveloppe and shows the RF focusing effect. Figure 6 shows the initial and final transverse emittances. Calculated normalized RMS final emittance is 0.8 π mm.mrd for 0.66 initially (1π mm.mrd. unnormalized at 100kV) i.e. negligible emittance growth

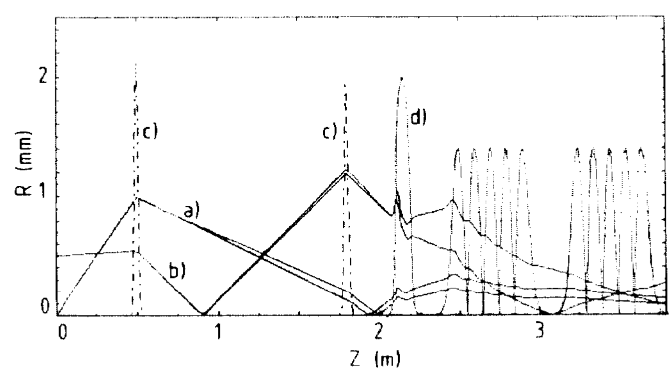

Fig. 5 - Trajectories for extreme phases (± 30 °). Initial conditions : origin is at the prebuncher cavity. (a) r = 0, angle = 2 mrd ; (b) r = 0.5 mm, angle = 0 ; other curves in arbitrary units (c) magnetic focusing field ; (d) maximum axial accelerating field

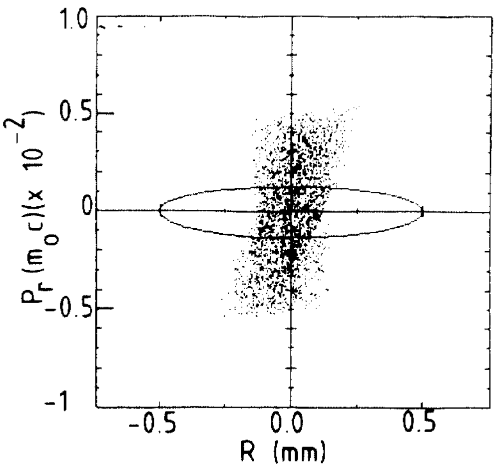

Fig. 6 - Final transverse emittance computed by "GRHF". The solid line ellipse represents the intial emittance

Space charge effect

Due to the low radial and axial beam dimensions and despite the low intensity that we have supposed (100 µA), space charge is not quite negligible. Figure 7 shows the final phase histogram successively with no space charge, with space charge, and with space charge and reoptimized prebuncher maximum voltage (2.08 instead of 1.93 kV). We can conclude that the space charge effect can be compensated by increasing slightly the prebuncher modulation. In the transverse phase space, emittance remains unchanged and so does the beam radius.

This result, justifies the method of calculation we have followed consisting in neglecting space charge forces in initial runs.

Conclusion

Using a single cell cavity as a preaccelerator structure, permits a good capture of electrons in velocity of light multicell cavities despite the fringing field and a standard high voltage electron gun.

Acknowledgements

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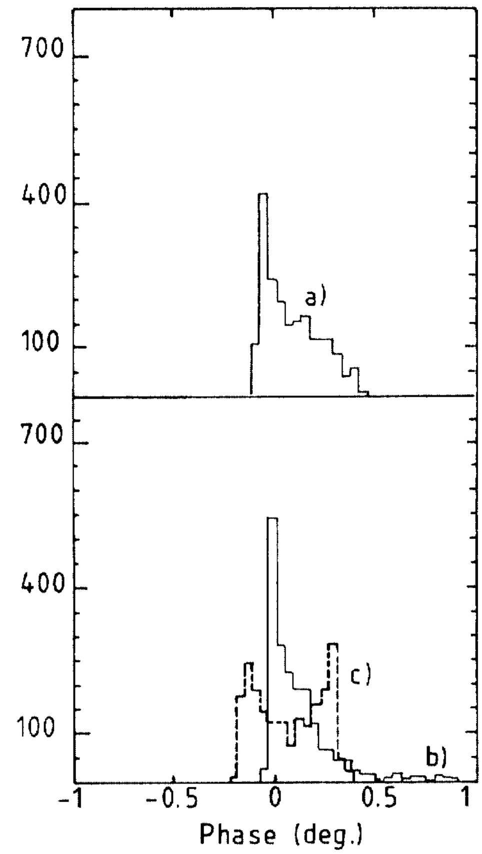

Figure 7 - Parmela computed phase histogram : a) without space charge ; b) with space charge ; c) with space charge and corrected prebuncher voltage.

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