THE MACSE INJECTOR

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Abstract

The MACSE injector will deliver a dc beam of about 100 μA. It is composed of two parts [1]:

- First a beam line, originally built by the University of Illinois, that insures the emittance definition, the chopping and the prebunching of the beam delivered by a 100 kV dc gun.

- Secondly, a superconducting capture cavity that accelerates the electrons up to about 2 MeV. It consists of one superconducting five-cell 1.5 GHz 0.84c niobium cavity. The beam dynamics has been analysed in longitudinal and radial spaces for different levels of the accelerating field. For an initial 60° bunch, a final phase extension of 1° is expected with an energy dispersion less than a few keV.

I) Introduction

MACSE is an experimental superconducting electron Linac. It consists essentially in one cryostat containing four 5-cell 1.5 GHz niobium cavities [1]. One problem we have had to solve is the capture of the low energy electrons delivered by the 100 kV gun. It could have been possible to inject the electrons from the gun directly into the first standard 5-cell cavity, provided that the gun high voltage be increased well above the level of 100 kV. More precisely, a 200 kV gun could permit a satisfactory capture. But since we were offered to use a 100 kV beam forming line already built by the University of Illinois five years ago, we chose to stick to that initial energy. Another option could have been to use a copper β graded capture cavity as CEBAF did [2], but we prefered to test the possibility of making a fully superconducting accelerator. The idea of using a superconducting β graded cavity was rejected as too complicated, at least in a first step. Of course, a monocell cavity could have worked from the beam dynamics point of view [3], since its field gradient can be higher than in a multicell cavity. Nevertheless, this solution was also rejected because it would have required the development of a RF power source as well as a cryostat quite different from the standard ones. The solution we finally adopted is using a reduced β = 0.84 five-cell cavity (i.e the length of each cell is 84 mm instead of 100 mm). Its power source will be the same as the others and the cryostat quite similar to the main one.

II) The 100 kV beam forming line

The University of Illinois built this beam line for a 450 MeV microtron project that finally remained unfounded [4]. Its design has been inspired from the equivalent beam line previously built at NIST [5]. All the elements of the line were transfered to Saclay, as part of a cooperation contract. The three RF cavities (two choppers and one buncher) could not be reused because of the difference of frequency. We ordered from Los Alamos Laboratory a new set of 1.5 GHz cavities identical to CEBAF's ones. The electron gun itself comes from Hermosa Electronics [6].

In addition to the gun, the beam line includes:

- *a set of two isolated apertures* for emittance limitation and definition. Given that the diameters of these apertures are respectively 1 mm and 8.5 mm and that their relative distance is 700 mm, the initial emittance will be limited to 2.7 π mm mrad.
- *a chopper* made of two identical square cavities distant from 1.35 m, each one being powered with two orthogonal modes (TM210 and TM120). A 60° arc-shaped aperture located in their mid-distance selects the wanted phase extension. The second cavity compensates for the deflection induced by the first one.
- *a buncher* consisting in a TM010 cylindrical cavity. The drift space between this buncher and the first iris of the capture cavity is 2 m long.
- *beam monitors*: view screen, wire scanner and ferrite toroïds for beam intensity measurements.

III) Choice of the capture cavity reduction factor.

In order to understand qualitatively the capture phenomenon by a non-graded standing wave cavity, one can represent it as an travelling wave structure with a constant phase velocity. This is equivalent to neglecting the reflected wave and the fringing fields. The problem becomes thus classical [7] and one can calculate the optimum phase velocity βc. Assuming 100 keV electrons and an accelerating field of 7 MeV/m, one finds β = 0.985. A more realistic simulation has been performed. Starting with an already built 5-cell cavity, we "compressed" its axial field profile by a factor β between 0.8 and 0.9 (Figure 1). The optimum value was found to be β = 0.84. Given this value, we have calculated a new cavity tuned at 1.5 GHz, in particular its actual axial field law which then was different. Its performances in longitudinal and radial spaces have been tested by a simulation taking into account the prebunching system. Figure 2 gives an evaluation of the capture efficiency for three levels of the accelerating field and figure 3 shows the electron energy variation along the cavity. The effect of the fringing field at the entrance is visible.

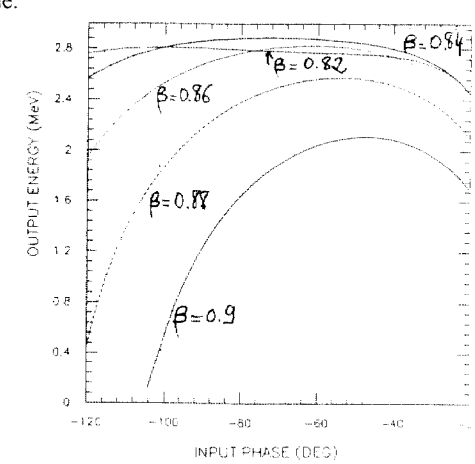

Figure 1: Variation of the energy at the output of the capture cavity with respect to the input phase for different value of the pitch of the cells (measured by the parameter β)

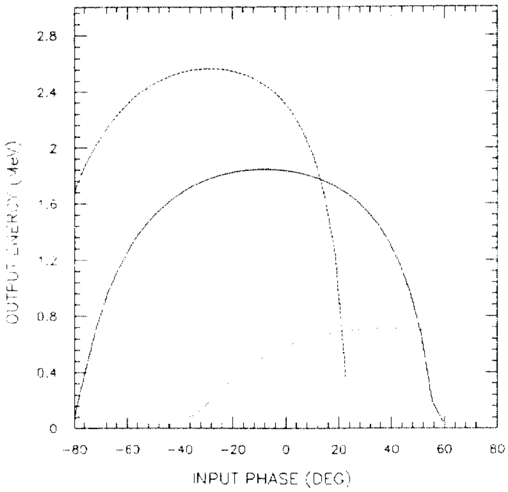

Figure 2: Energy gain in the capture cavity as a function of the input phase for three levels of the accelerating field (2.5 MeV/m, 5 MeV/m, 7 MeV/m)

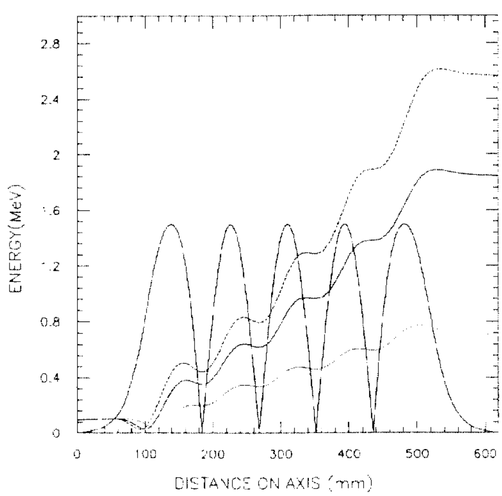

Figure 3: Electron energy variation along the cavity for three levels of the accelerating field (2.5, 5., 7. MeV/m). The dotted line represents the envelope of the field.

IV) Beam dynamics.

As mentionned in a previous paper [3], we use a locally written code called GRHF to determine the main properties of the accelerating cavities. The space charge effects are neglected in a first step, and then estimated with the well-known code PARMELA.

Using superconducting cavities introduces two difficulties that do not exist for room temperature ones:

1) The large iris diameter needed by HOM transmission results in a far extending fringe field at both side of the capture cavity. At the entrance, this fringe field decelerates the electrons and thus deteriorates the capture efficiency.

2) The accelerating field that the electrons will encounter is not *a priori* well-known unlike in copper structures. The performance of the cavity may vary within a large range after fabrication and evoluate in time. It is nevertheless necessary that the bunching remains effective in all cases. We have checked its efficiency for different levels of the accelerating field.

IV-1) Optimization of the input phase of the electron bunches.

We have calculated all the input conditions in the longitudinal phase space (energy and phase) which lead to a given value of the energy at the output of the capture cavity. The general shape of these "iso-energy" curves is the following (Fig. 4):

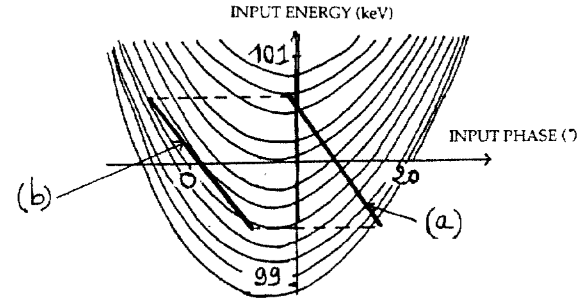

Figure 4: Iso-energy curves at the output of the capture cavity in the energy-phase space (4 keV between two curves). Segment (a) represents the position of the intput emittance that maximizes the output energy. Segment (b) represents the position that minimizes the output energy dispersion.

In the energy-phase space, the emittance at the entrance of the cavity can be approximated by a straight line segment, the slope and length of which are determined by the adjustments of three parameters of the beam forming line: drift space length, amplitude and phase of the RF field of the bunching cavity. Its position along the phase axis is fixed by the phase of the cavity field. Its optimal value is the one that minimizes the energy dispersion at the output of the capture cavity. It can be graphically estimated since it corresponds to the situation where the emittance segment intersects the smallest number of isoenergy curves as possible. Furthermore, it happens that this criterion leads also to an output phase extension which is near its minimal value. This comes from the fact that "iso-phase" and "iso-energy" curves have approximately the same structure. Figure 5 shows the result of the optimization.

We have used the code PARMELA to estimate the effect of the space charge on the dynamics of the 100 keV bunches between the prebuncher and the capture cavity. The space charge forces tend to oppose bunching. This effect is found negligible if the intensity is lower than 100 μA. It cannot be ignored beyond this limit but can be compensated by increasing slightly the voltage of the buncher.

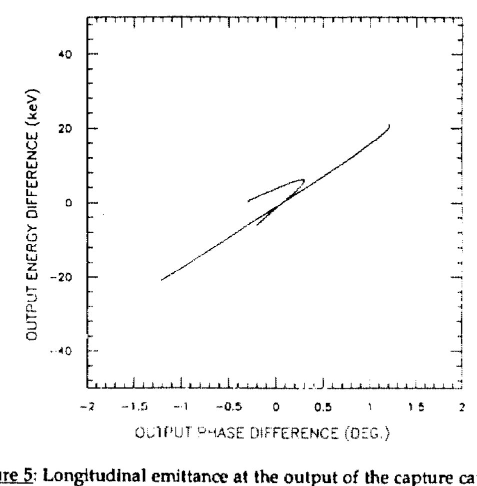

Figure 5: Longitudinal emittance at the output of the capture cavity before and after optimization. The phase of the cavity which maximizes the output energy gives an energy dispersion of 40 keV and a phase extension at the output of 3°. Those quantities can be respectively reduced to 7 keV and 0.5° if the phase is shifted to its optimal value.

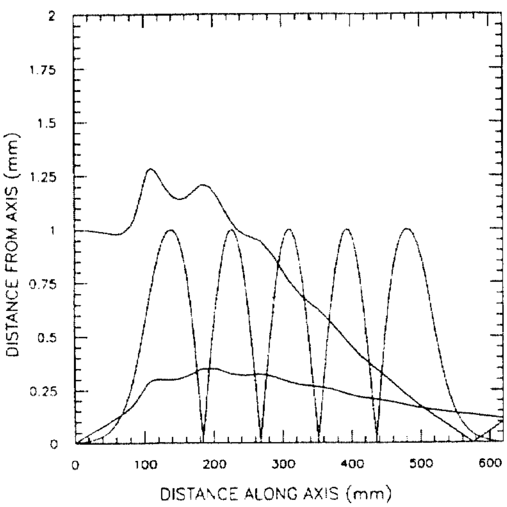

Figure 6: Two electron trajectories showing the focusing effect of the capture cavity. The dotted line represents the envelope of the field.

IV-2) Radial dynamics.

It is well-known that the cavities have a strong focusing effect at low energy. For the three last MACSE cavities we have used a formalism developped by Chambers, which works only for high energy electrons [8]. Instead, matrices of the low energy cavities have been determined by our simulation code. The focal length of the capture cavity is of the order of the cavity length (Figure 6). One can notice that the beam is first defocused at the entrance of the cavity by the fringing field.

V Conclusion

A sheme for a fully superconducting electron injector has been investigated and demonstrated efficient. It is presently being assembled. The 0.84c five-cell cavity has been tested with RF in cryogenic conditions and works quite satisfactorily. First beam is expected for the end of this year.

Acknowlegments

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