A High Charge per Bunch Injector for the TESLA Test Facility using a Normal Conducting Capture Section

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Introduction

Because of the difficulties to find a classical scheme of injector (not a RF gun), achieving the specifications of the TESLA test facility "Injector 2" [1], and using superconducting cavities as capture section [2], we have studied a solution using a room temperature accelerating structure. Some basic parameters are discussed and preliminary computer simulations are presented.

Parameters of the accelerating structure

We started with the hypothesis of a gradient

$$E = 15 \text{ MV/m}$$

in the capture cavity. Such a high gradient is necessary to counteract space charge forces in the electron bunch and and to rise quickly the electron energy to the level where they cancel.

Because of the required 1% duty cycle, we will need a structure able to withstand a high average power. All structures that have been optimized in this respect operate in the standing wave mode. One of the most performing has been designed and is now in operation at Mainz, in the MAMI facility [3]. At the RF frequency of 2.45 GHz and for the β=1 case, the reported shunt impedance is Rs=77 MΩ/m , what gives Rs=56 MΩ/m at 1.3 GHz as TESLA is.

The average power dissipation rate in the structure is given by

$$dP/dZ=(E^2/R_S).(d.c)$$

d.c being the duty cycle. We need, therefore, a structure able to dissipate 40 kW/m.

In taking, now, a structure of 5 cells, i.e 0.576 m long, a peak power of 2.3 MW will be necessary. We assume available a klystron capable to deliver it, at the required pulsed regime.

The Mainz structure is reported to be limited at 22 kW/m but, after the authors, it could withstand 2 or 3 times more with only a minor modification (redesign the tuner cooling).

As more water pipes can be put around bigger cavities, the capability of heat removal should scale linearly with (frequency)$^{-1}$. This gives us another safety factor of almost 2.

However, it has to be pointed out, that the Mainz figure has been obtained in C.W operation : the gradient was 1.2 MV/m only. To work in our mode, it will be necessary to make sure that the higher peak power and gradient can be withstood during 1 ms pulses, and that the resulting transient detuning due to the thermal stress can be compensated, not to speak of arcing or multipactoring. For this preliminary study, we have disregarded these questions.

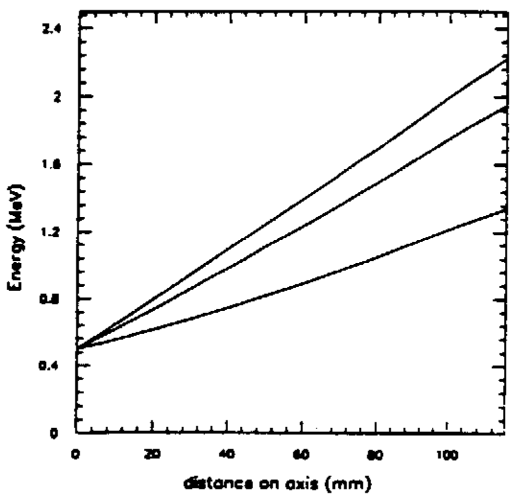
Choice of the gun High Voltage.

Most existing high intensity injectors use an electron gun working in the 100-200 kV range. However, it is well known that better bunching and capture require higher initial energy, and some linacs work with a 400 kV gun [4]. A high brightness 500 kV gun has been recently built and tested [5], though for an intensity 10 times lower than the one we need, and is commercially available [6].

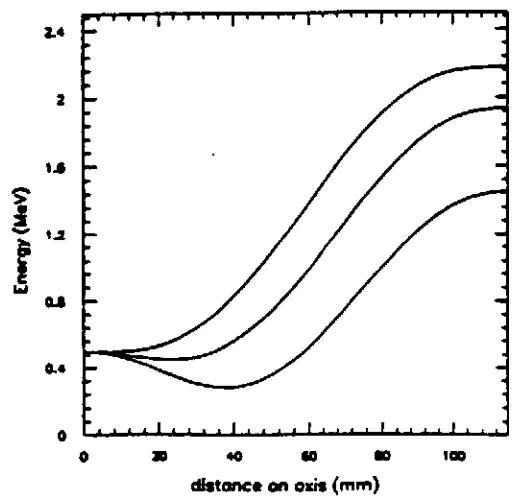
Working above the 250 kV limit is rarely done because it requires a very unconvenient SF6 tank for the gun and its controls. In addition, equipment prices grow very fast. In our scheme, we nevertheless chose this value for 2 new reasons :

1- It will avoid to have to use a β graded cavity as in most existing high intensity injectors. Such a cavity may be straightforward to design and operate at low power, but much more complicated in the case of the high power structure we need.

2- Most existing high intensity injectors use a T.W structure for electrons capture. Working with a S.W accelerating cavity results locally in a low acceleration or even in a deceleration for electrons far in phase from the center of the bunch (fig.1). In the first cell of the capture cavity or in its fringe field , the variation of the electrons velocity and therefore of their relative phases will be smaller if they start with a very high energy.



(a)



(b)

Fig. 1 : Comparison of electron energy gain in the first cell of a traveling wave (a) and a standing wave (b) capture cavity for 3 input phases (phase of maximum energy, +20°, +20°).

Prebunching scheme

As a gun can deliver pulses as short as 1 ns, the frequency of a first prebunching cavity can be taken at 216 MHz for this pulse to be placed in the linear region of the electric field oscillation. A second one, operating at 433 MHz, has been found efficient if placed 2.5 m farther and 1 m before the capture cavity. The maximum amplitude of the modulations are respectively 120 and 250 kV.

These results are optimum only with respect to the level of the precision of our simulations : the model used in the code PARMELA for the prebunching cavities, is nothing but a theoretical zero length gap where a sinusoidal voltage is applied. Another simplification is made in describing the accelerating field in the capture cavity as a pure sinusoid (a more realistic representation can be made when we better know the Mainz structure). Our purpose was first to demonstrate the validity of the scheme in the beam dynamics aspect, not yet to devise a real system.

The cavity maximum voltages we have found do not take a power limitation into account. If, in devising a real model, such a limit were encountered, it would be possible to put 2 successive cavities instead of one or, even, to use a multicell structure instead of a single gap cavity. For instance, up to 4 different cavities are used in the Osaka injector [7] and a 5 cell structure is used as a prebuncher in the Argonne linac [8]. Of course, new distances between cavities would then be found.

Focusing

One of the advantages of this scheme over those using S.C cavities is that solenoidal focusing can be used all over the accelerating structure. As space charge forces introduce a strong coupling between transverse and longitudinal space phase, such a focusing system allows to find a compromise between them. It is found that a good way to do, is to let large beam radius in the long drift spaces where space charge forces make the emittance grow and to concentrate radially the beam in the RF structure to reduce the effect of RF transverse forces.

Again some simplification is introduced by PARMELA in describing magnetic fields as perfect solenoids.

Magnetic bunching

As in several existing injectors [9,10] the required final bunching is obtained in setting the accelerating RF phase in a way to create a correlation between the energy and the position of the particles in the bunch and in making the beam go through a magnetic chicane. This part was not simulated with PARMELA. We only applied the corresponding transformation to the relative longitudinal positions of the particles computed in the preceding system. As it can be done in a real system by putting slits in a region of energy dispersion, an energy limitation has been introduced to suppress a long, low intensity tail of the energy spectrum. It is found that a path lengthening of the order of 1 cm/MeV is suitable. It can be obtained with a 4 magnets scheme (fig 2), derived from the 3 magnets scheme described in [11], with magnetic fields of 200 Gauss [12].

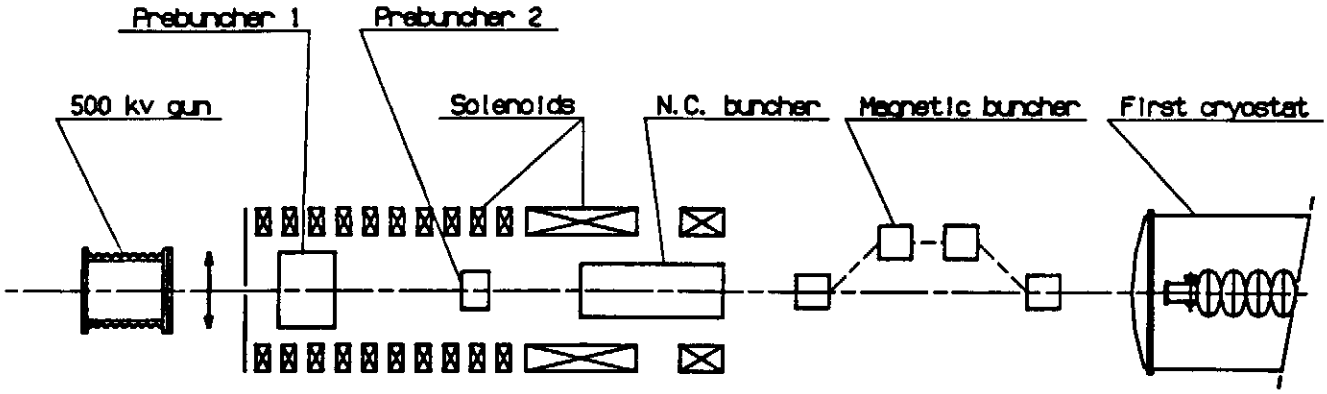


Fig. 2 : Schematic of the proposed injector with the magnetic buncher using 4 magnets.

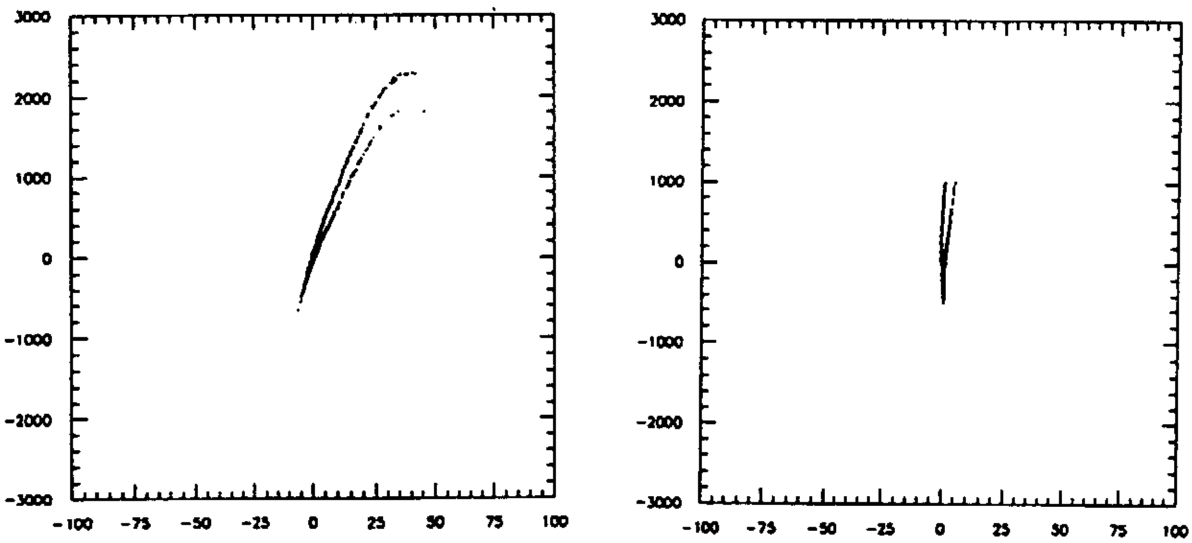
Final results

Results are presented in figs. 3, 4 and 5.

The beam energy is 7 MeV. The rms bunch phase extension is 2.1 degree what corresponds to a length of 1.3 mm. The rms energy spectrum width is 700 keV after the limitation. Having started the computer run with 1000 particles representing 5.10^{10} electrons, 870 are left i.e 4.35 10^{10} electrons in the bunch.

Final normalized transverse emittance is found equal to 120 π mm.mrad i.e 3.5 times the initial emittance.The initial transverse emittance is 34 π.mm.mrad and results from a scaling of the already quoted 500 kV gun [4] that had been measured for a lower intensity.

The rms beam radius (fig. 5) is as big as 7 mm in the long drift space and is reduced to 2 mm in the accelerating structure. Corresponding solenoidal fields are respectively the order of 100 and 1500 Gauss.



(a) (b)

Fig. 3 : Output energy (keV) vs Output phase (deg).
(a) : Before the magnetic bunching (at the end of the capture cavity)
(b) : After the magnetic bunching and the $\Delta E = 1$ MeV limitation.

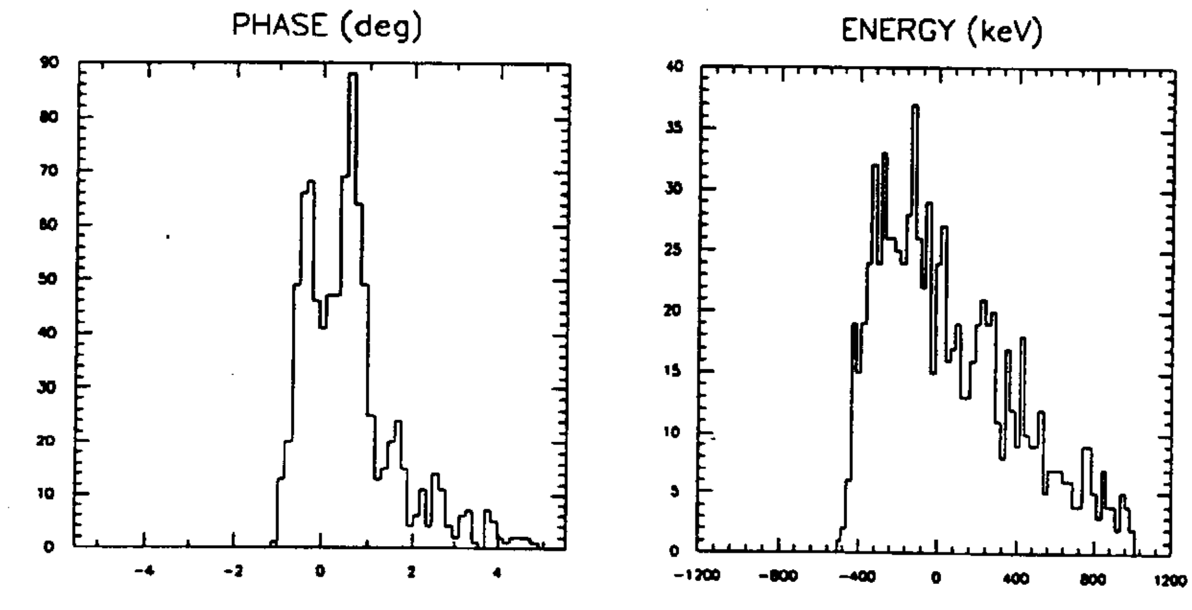


Fig. 4 : Phase and energy histograms generated by Parmela, corresponding to fig.3(b) plot. Of 1000 initial particles, 870 are left. Average final energy is 7 MeV.

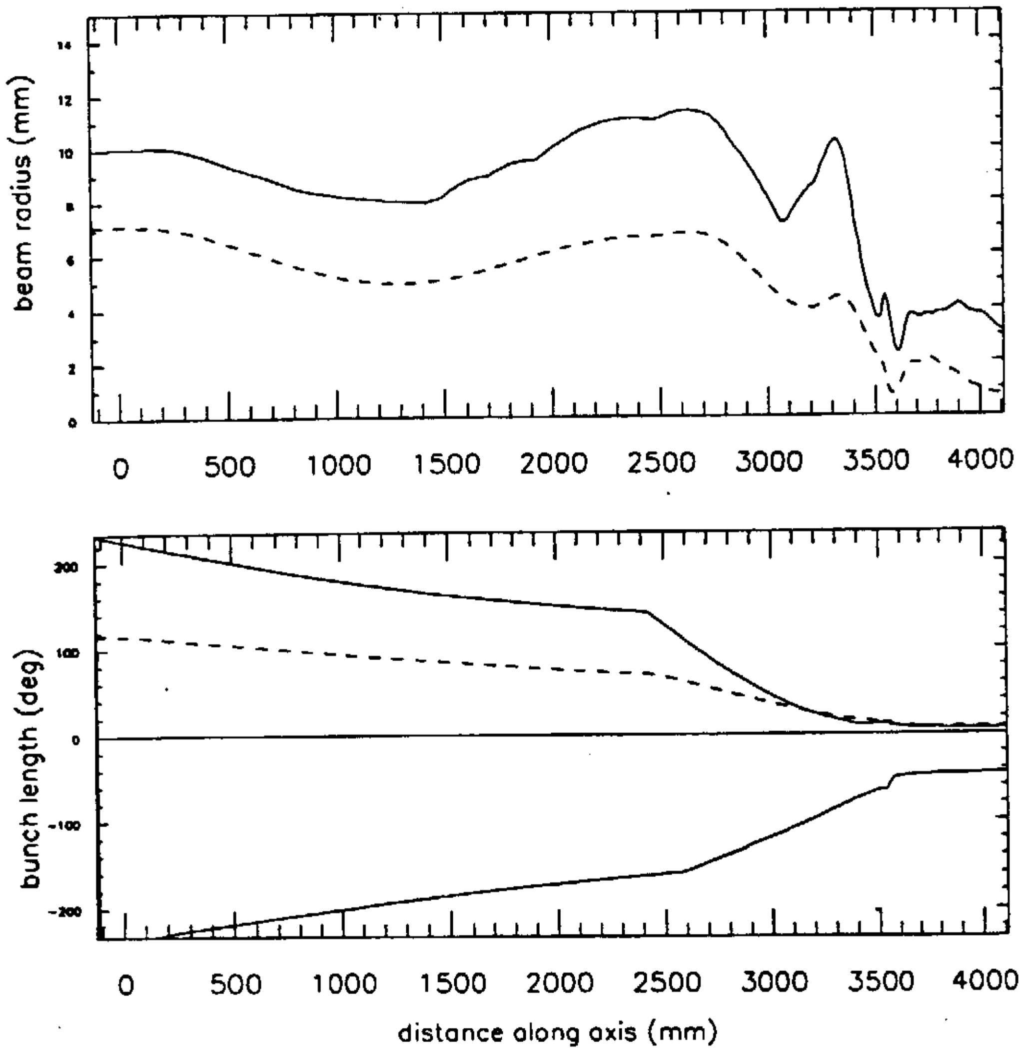


Fig. 5 : Beam radius and bunch length variation in the prebunching drift spaces and in the capture cavity calculated with Parmela (dotted lines show rms values).

Origin is at the first buncher (216 MHz) location. 2nd buncher (433 MHz) is at z=2500 and capture cavity starts at z=3500.

Conclusion

Though important simplifications are made in the representation of the elements, we believe that a conventional room temperature injector for the TESLA test facility could be built if it is verified that the proposed accelerating structure can work under 1 ms pulses of 2 MW of peak power and 15 MV/m electric field.

It may be interesting to mention that just after this study had been completed, we have ran into a paper from the Chalk River Laboratory about the design of a structure dissipating 300 kW/m [13]. This could justify a new study.

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