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Updated Beam Dynamics for a CTF3 Injector

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A CTF3 drive beam injector for the nominal stage is proposed, which includes thermionic DC gun, three Sub-Harmonic Bunchers (SHBs), one prebuncher, one 6-cell travelling wave buncher and two accelerating structures. Its beam dynamics is simulated by PARMELA. It is shown that all important parameters, e.g. satellite charge, bunch length and normalized transverse emittance can be met with the design goals if about 400 kW RF power for 3 SHBs is available. In addition, the beam dynamics of the injector for the initial stage has been simulated.

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A CTF3 drive beam injector for the nominal stage is proposed, which includes thermionic DC gun, three Sub-Harmonic Bunchers (SHBs), one prebuncher, one 6-cell travelling wave buncher and two accelerating structures. Its beam dynamics is simulated by PARMELA. It is shown that all important parameters, e.g. satellite charge, bunch length and normalized transverse emittance can be met with the design goals if about 400 kW RF power for 3 SHBs is available. In addition, the beam dynamics of the injector for the initial stage has been simulated.

1 Introduction

A new phase of the CLIC Test Facility (CTF3) has been approved, which is an intermediate step to demonstrate and to test many critical components of the CLIC project [1]. It is foreseen to be built in 3 stages and the injector will also have 3 stages of development. The first one is called preliminary stage. Its injector is the same as the present one used for LIL [2] except of the thermionic gun. The second phase is called initial stage. Its injector will have a completely new layout. The final one is called the nominal stage. Its injector is very similar to the initial phase injector except that subharmonic bunchers (SHBs) are installed in order to generate even and odd trains with every other bucket filled.

This paper mainly focuses on the nominal stage. For this stage the satellite charge should be kept as small as possible in order to get maximum RF power production efficiency and minimum beam losses. The required bunch length is 12 ps fwhm and the emittance should be less than 100 π·mm·mrad in order to get sufficiently small beam sizes in the downstream accelerator components. The bunch charge at the injector exit is required to 2.33 nC. To meet these stringent beam parameters many schemes have been investigated and compared [3,4,5,6]. This paper focuses on our proposal which includes a thermionic gun, 3 SHBs, one prebuncher, a 6-cell buncher and two accelerating structures. Its beam dynamics are simulated extensively with PARMELA.

In addition, it has been studied if the same injector configuration can be used for the initial phase if the SHBs are omited and an additional prebuncher is inserted.

2 Proposal of the bunching system

The bunching system consists of a 3 GHz prebuncher and a travelling wave tapered phase velocity buncher accelerator. The one standing wave prebuncher needs about 30 kV for optimum bunching. The distance between the prebuncher and the buncher is optimized to 8.5 cm.

For optimum bunching, many versions of the buncher configurations have been extensively investigated. With comparisons, a 6-cell travelling wave accelerator with tapered phase velocity is adopted. It is shown that the cells in the buncher need to start at a phase velocity of 0.7 c_o gradually increasing up to 0.81 c_o. Further, the iris radius and accelerating gradients in the 6 cells are optimized. Table 1 gives the optimization results. It is shown that version 3 is the best. Satellite charge is smaller and not too sensitive to the accelerating gradient. In addition, simulations show that the transverse HOM mode frequency is well separated from the fundamental accelerating mode for this version [7].

Table 1: comparisons with different buncher structure

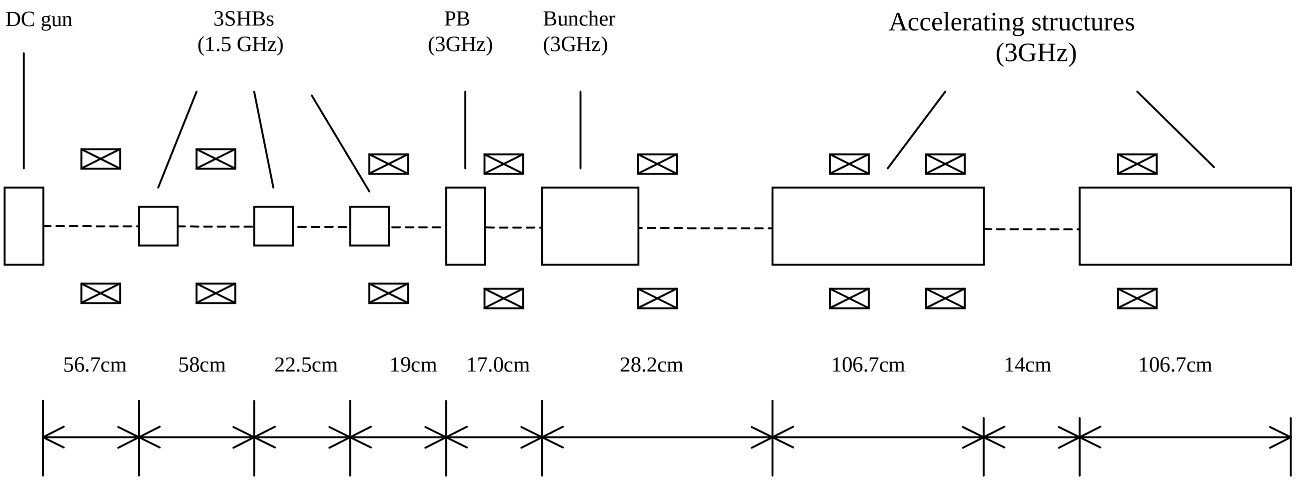
	Iris radius (cm) in 6 cells	Gradient (MV/m) in 6 cells	Satellite (particle no. in main bunch)	RF power for 3shbs (voltage of 3 shbs)
Ver. 1	1.70/1.52/1.52/1.52/ 1.52/1.52/1.52/	b) 3.5/3.5/3.5/3.5/3.5/3.5/ a) 4.5/4.5/4.5/4.5/4.5/4.5/ c) 5.5/5.5/5.5/5.5/5.5/5.5/	a) 6.0% (907) b) 6.0% (1197) c) 6.5% (1275)	320 kw (14/14/16 kV)
Ver. 2	2.30/2.33/2.36/2.40/ 2.43/2.46/2.50/	a) 5.0/5.1/5.2/5.3/5.4/5.5/ b) 5.5/5.5/5.5/5.5/5.5/5.5/ c) 5.5/5.6/5.7/5.8/5.9/6.0/	a) 6.4% (1132) b) 6.3% (1155) c) 6.7% (1194)	400 kw (16/16/16.8 kV)
Ver. 3	1.7/2.12/2.16/2.20/ 2.24/2.28/1.7	a) 5.0/5.0/5.0/5.0/5.0/5.0/ b) 5.0/5.1/5.2/5.3/5.4/5.5/ c) 5.5/5.5/5.5/5.5/5.5/5.5/	a) 4.9% (1149) b) 5.0% (1192) c) 5.0% (1194)	400 kw (16/16/16.8 kV)

Note:

*: rf power is calculated from new formula provided by Igor [8].
* their other beam parameters, bunch length, energy spread, emittance, except the satellite charge are almost the same

3 Beam dynamics of the injector

Through many simulations and comparisons, a injector for CTF3 has been proposed. Its layout is schematically shown in Figure 1. It is composed of a 140 keV thermionic Gun, three 1.5 GHz SHBs, one 3 GHz prebuncher and a 6-cell travelling wave (TW) tapered phase velocity buncher as described in section 2 and two 32-cell TW accelerating structures. All components downstream of the gun are embedded in a solenoid field.



Note: SHB’s length=4 cm, PB’s length=4 cm, Buncher’s length=15.2 cm

Figure 2: Schematic layout of CTF3 injector proposal

3.1 Longitudinal beam dynamics

We start the simulations from the gun exit. There the kinetic energy is 140 keV and the normalized emittance is assumed to be 5 π·mm·mrad. A total of 6000 input particles are distributed over 6 S-band cycles is started for the simulations. Beam current at the gun exit is 5.7 A in order to guarantee the current of 3.5 A at the end of the injector.

The main objective for the simulations is to make the satellite charge (in a 20^0 S-band window) less than 5% of the main bunch (also in a 20^0 window). The satellite signal is defined as [9]:

$$\delta = \frac{N_1}{N_2},$$

where N_1 is the particle number of the satellite within the range of a 20^0 window, N_2 is the particle number of the main bunch within the range of a 20^0 window. It is well known that the fewer particles in the satellite bucket, the higher RF power for 3 SHBs will be needed. However, the high RF power for 3 SHBs implies high costs for the 1.5 GHz RF-sources. Thus, the needed RF power for SHBs should be as low as possible while the satellite charge is controlled below 5% of the main bunch. Another point is to make the bunch length as short as possible while the satellite charge is still controlled below 5% of the main bunch [10].

The beam dynamics with 400 kW RF power for 3 SHBs are calculated by PARMELA. The phase space projections at the end of the injector are shown in Figures 2.

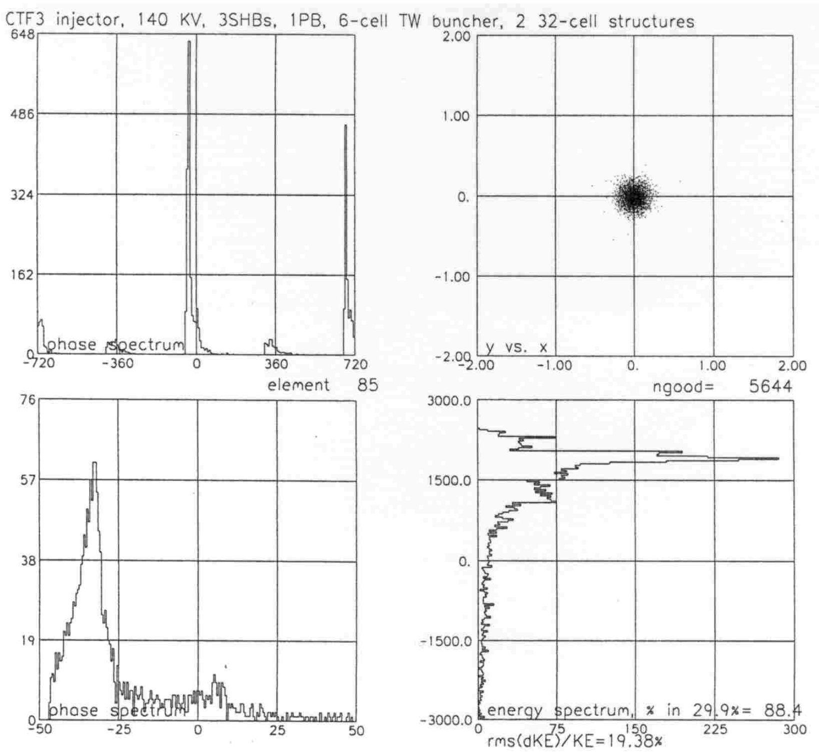


Figure 2: Phase spaces for the nominal stage with 400 kW RF power

It is shown that its micro-bunch width at the end of the injector is near 10 ps (FWHM) and about 70% particles are captured in a 20^0 window. A fraction of particles are in the tail of the main bunch and outside of the 20^0 window, these particles will be cut off by scrapers in a dispersive section downstream of the injector. The charge in the satellite bucket is about 5% of the main bunch.

3.2 Transverse beam dynamics

Two accelerating structures start at about 200 cm of longitudinal position along the beam line. Here, the emittance at the end of the injector is measured, as shown in Figure 3, with different solenoid field in the two structures as shown in Figure 4. The emittance may become lower if the tail in the bunch is cut off. It is shown that the emittance difference with different solenoid field is not too large. However, beam envelopes with different solenoid field settings are different, as shown in Figure 5. It is presented that the beam envelope with 500 Gauss is larger than that with 2000 Gauss by a factor of 2, however, the beam envelope with 1000 Gauss is close to the one with 2000 Gauss. The beam size at the injector with different solenoid field is shown in Figure 6. It is clear that the beam sizes with both 1000 Gauss and 2000 Gauss are smaller than the beam size with 500 Gauss field. Further comparing beam sizes of 1000 Gauss and 2000 Gauss, it is found that there are more halo particles with 2000 Gauss. In addition, the bunch length with 1000 Gauss is better than the one with 2000 Gauss. Considering these points, 1000 Gauss solenoid field is used for our final simulations.

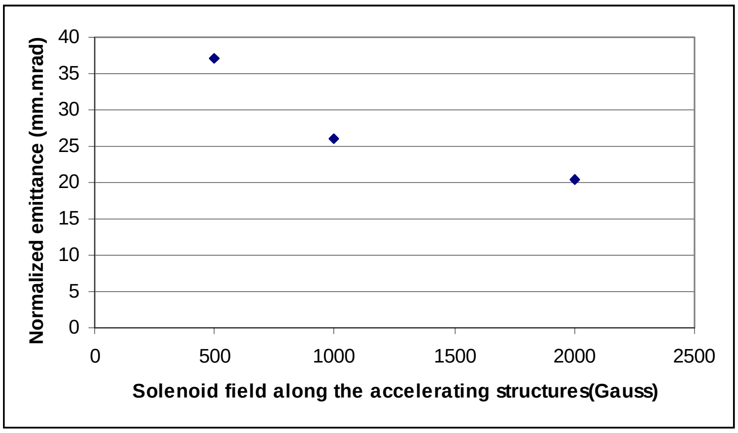


Figure 3: Emittance vs solenoid field in the accelerating structures

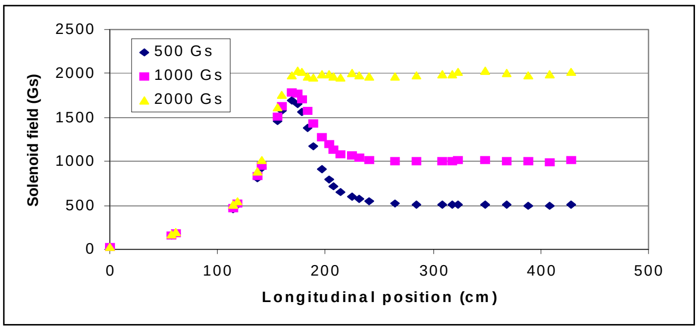


Figure 4: Different solenoid field distribution along the injector

4 Beam parameters for CTF3 initial stage

The nominal stage injector can also be used for the initial phase if the three SHBs are switched off and an additional prebuncher is inserted. The beam dynamics for this case has also been simulated. Only after optimizing the voltages of both the prebunchers to be around 30 kVs, the design goals can be met. Phase space projections at the injector output are shown in Figure 7. The beam parameters are summarized in Table 2.

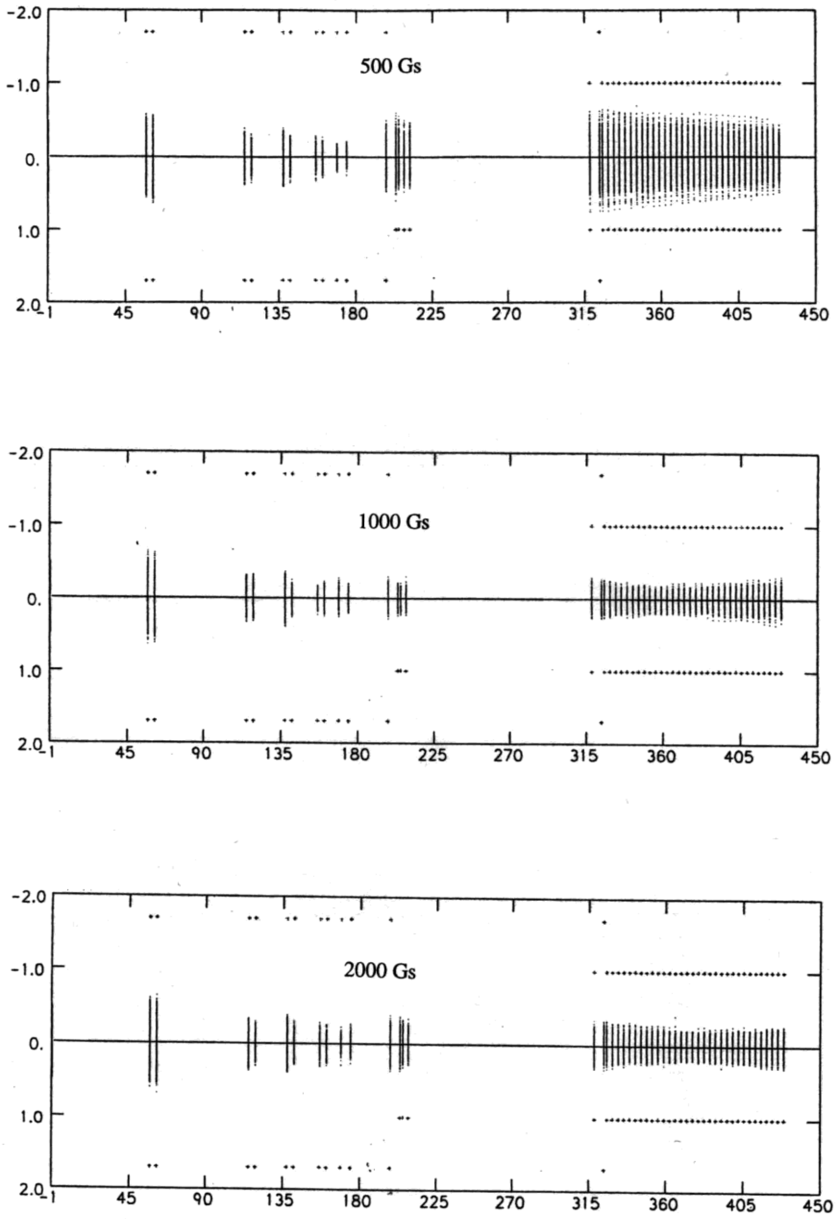


Figure 5: Beam envelopes with different solenoid fields

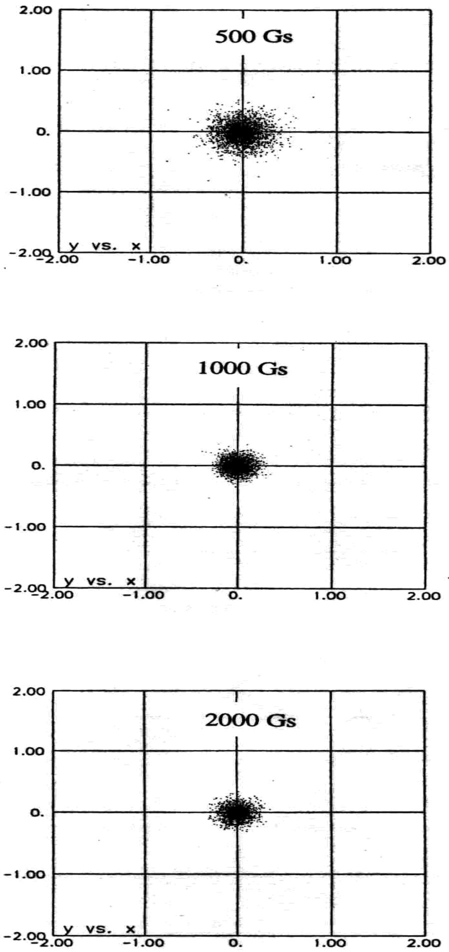


Figure 6: Beam sizes with different solenoid fields

Table 2: Beam parameters for the initial stage

	Simulated	goal
Bunch length (FWHM, pS)	10	<12
Bunch length (FW, ps) (cutting the tail)	~20	---
Energy spread (FWHM, MeV)	~0.3	<0.5
Energy spread (Full Width, MeV)	~1	--
Normalized emittance (mm.mrad) (non-cutting the tail, 1kGs field)	16	<100

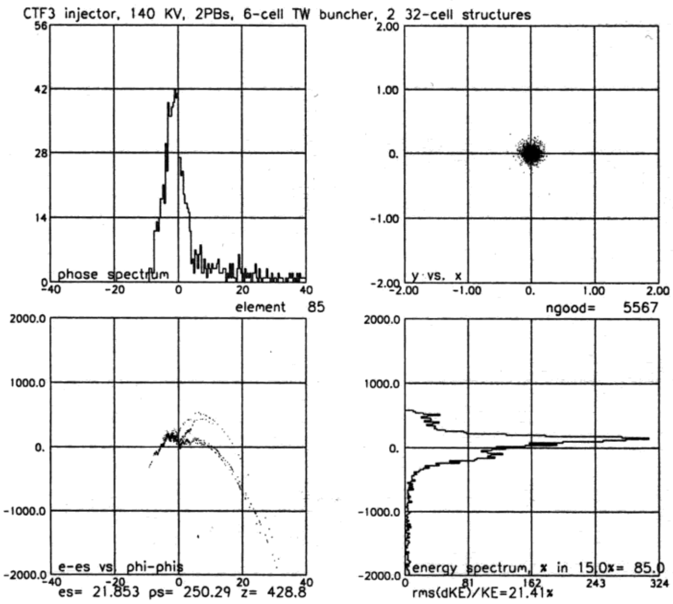


Figure 7: Phase spaces of the initial stage

5 Conclusion

The beam dynamics of the CTF3 injector with three SHBs, one prebuncher and one TW buncher and two structures have been simulated. The main beam parameters for the initial and nominal stages are compared with the required performance, as summarized in Table 3. It is shown that all key parameters except of the final energy can be met when about 400 kW RF power for 3 SHBs is available. The final energy can be increased by adding a third accelereating structure fed by the output coupler of the buncher. This is possible since the RF-power transmitted through the buncher will be barely attenuated.

Table 3: Comparison between the simulations and the requirements

	Initial stage	Nominal stage	Goal
RF power for 3 SHBs	---	Low enough	380 kW
Satellite	---	5.1%	<5.0%
Bunch length (FWHM, ps)	<10	10	<12
Bunch length (Full Width, ps) (cutting the tail)	~20	~20	---
Energy (MeV)	~20	~20	26
Energy spread (FWHM, MeV)	0.3	0.3	0.5
Charge/bunch (nC)	1.14	2.25	2.33 (1.17)
Normalized RMS emittance (mm.mrad) (non-cutting the tail, 1k Gauss field)	16	26	<100

6 Acknowledgements

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