Design Studies for a High Current Bunching System for CLIC Test Facility (CTF3) Drive Beam

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Abstract

A bunching system is proposed for the initial stage of CTF3 which consists of one (two) 3 GHz prebuncher(s) and one 3GHz travelling wave (TW) buncher with variable phase and group velocities. The electron beam is emitted from a 140 KV DC gun. Since the average macropulse beam current (3.5 A) at the exit of the TW buncher is rather high, inside the TW buncher one has to take the beam loading effect into consideration. By using PARMELA, it is shown numerically that the bunching system can provide the bunches which properties satisfy the design requirement of CTF3. The 0.8 meter long TW buncher working at $\frac{2\pi}{3}$ mode has two phase velocities, $\beta = 0.75$ and $\beta = 1$. The dimensions of the cavities in the two phase velocity regions are proposed by considering the beam loading effect. The transient beam loading effect and the multibunch transverse instabilities are studied numerically. It is concluded that higher order mode (HOM) couplers should be installed in the TW buncher with the loaded quality factor of the dipole mode lower than 80.

1 INTRODUCTION

CLIC is a two beam accelerator (TBA) based e^+e^- linear collider. As other linear collider projects, such as NLC, JLC, and TESLA, CLIC evolves in terms of its conceptions and technologies. The recently proposed CLIC drive beam scheme [1] makes CLIC more interesting. To demonstrate the feasibility of the new drive beam scheme and to test other technical aspects, CTF3 [2] has been proposed as a natural successor of the existing CTF2 to which LAL has actively collaborated and contributed in the past years [3][4]. In this paper we will restrict oursevles to the study of the bunching system for CTF3 which is a new subject of collaboration between LAL and CLIC group of CERN.

The bunching system under study consists of a 140 KV DC gun, one (two) prebuncher(s) of 3 GHz for the initial stage and one TW buncher of 3 GHz. The design means choosing bunching system layout, parameters, and numerical simulations. In the following sections we will discuss the design of the travelling wave buncher considering the beam loading effect, the numerical simulations of the proposed bunching system by using PARMELA, the multibunch longitudinal and transverse beam dynamics in the TW buncher with the presence of long range wakefields.

2 BEAM LOADING EFFECT

We start with the power diffusion equation in a linac

$$\frac{dP(z)}{dz} = -2\alpha(z)P(z) - IE(z) \qquad (1)$$

where $P(z)$ is the power flow inside the structure, $E(z)$ is the amplitude of the synchronous accelerating field, and I is the average beam current during the rf pulse. By using the initial condition $E(0) = E_0$, one gets:

$$E(z) = E_0 \exp(-\alpha z)\sin(\phi) - IR_{sh}(1 - \exp(-\alpha z)) \qquad (2)$$

where $R_{sh}(z)$ is the shunt impedance of the accelerating mode, $E_0 = \sqrt{2\alpha P_0 R_{sh}}$ and P_0 is the input power from the rf source, $R_{sh}(z)$ and $\alpha(z)$ are kept constant within the accelerating structure, $\phi = \pi/2$ corresponds to the maximum acceleration, and this expression was first obtained by A.J. Lichtenberg [5].

To have good energy transfer efficiency and energy gain at the same time, one requires (fully beam loading condition):

$$E(L) = 0 \qquad (3)$$

where L is the length of the accelerating section. When the ohm loss on the structure wall is small the fully beam loaded condition results in

$$P_0 = \frac{IE_0L}{2} \qquad (4)$$

For a given E_0, I, and L, one gets P_0 from eq. 4 and one can determine the geometry of the disk-loaded structure by solving the following equations:

$$\frac{E_0^2}{P_0} = \frac{\omega R_{sh}}{v_g Q} = \frac{4k_{010}}{c(v_g/c)} \qquad (5)$$

where k_{010} and v_g/c can be expressed analytically as [6][7]:

$$k_{010} = \frac{2J_0^2\left(\frac{u_{01}}{R}a\right)\sin^2\left(\frac{u_{01}h}{2R}\right)}{\epsilon_0 \pi h D J_1^2(u_{01})u_{01}^2} \qquad (6)$$

$$\frac{v_g}{c} = \frac{\omega K_e D \sin(\theta_0)}{2c} \qquad (7)$$

$$K_e = \frac{4a^3}{3\pi h R^2 J_1^2(u_{01})}\exp(-\alpha_e d) \qquad (8)$$

$$\alpha_e = \left((2.405/a)^2 - (2\pi/\lambda)^2\right)^{1/2} \qquad (9)$$

where the definitions of a, h, R, D, and d are given in Fig. 1. Now we make a rough design for the TW buncher working at 3 GHz and 2π/3 mode. If one takes $E_0 = 10$ MV/m, $R = 0.04$ m, $I = 4$ A, $L = 0.8$ m, one finds $P_0 = 16$ MW and the structure dimensions given in Table 1. The structure has two sections with phase velocities $\beta = 0.75$ and $\beta = 1$, respectively. The number of the cells of $\beta = 0.75$ is four which has been determined by the beam dynamics simulations of PARMELA.

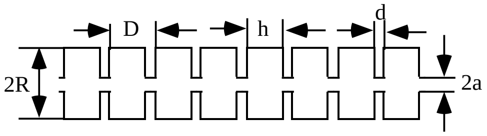


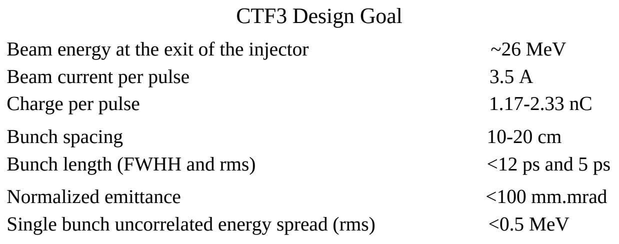
Figure 1: Disk-loaded accelerating structure

Cell type	D (m)	h (m)	a (m)	v_g
$\beta = 0.75$	0.025	0.0137	0.0146	0.031
$\beta = 1$	0.033	0.02	0.016	0.029

Table 1: summary of TW buncher dimension

3 BEAM DYNAMICS

The design goal and the layout of the bunching system are shown in Fig. 2, and in Fig. 3 [8][9]. A multibunch beam dynamics study shows that for the final phase of CTF3 the dipole mode in the TW buncher has to be damped to $Q_{L,110} \leq 80$ as shown in Fig. 4. By using PARMELA one gets the bunched beam parameters at the exit of the TW buncher. Limited by the space we show the simulation results in Fig. 5 only for the case of single prebuncher. The DC current coming from the cathode is 7 A and during 2π, 500 particles has been tracked. For the observing window of 20 degree centered around the bunch current peak, one gets: 322 particles, the normalized rms emittance is 51 mm.mrad, the rms energy spread is 0.12 MeV, the energy of the reference particle is 3.8 MeV, and the longitudinal rms bunch length is 4.4 ps. In future simulations two fully beam loaded structures will be added after the TW buncher to push the beam energy up to about 26 MeV.

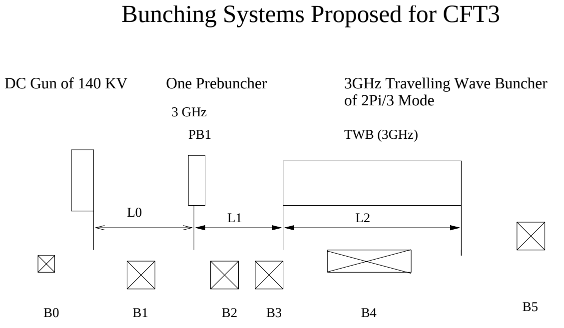

CTF3 Design Goal

Beam energy at the exit of the injector	~26 MeV
Beam current per pulse	3.5 A
Charge per pulse	1.17-2.33 nC
Bunch spacing	10-20 cm
Bunch length (FWHH and rms)	<12 ps and 5 ps
Normalized emittance	<100 mm.mrad
Single bunch uncorrelated energy spread (rms)	<0.5 MeV

Figure 2: The design goal.

4 CONCLUSION

In this paper we have given a preliminary design for the TW buncher. By using PARMELA the bunching system consisting one (two) prebuncher(s) and a TW buncher has been simulated and the results are satisfactory. More simulations will be done to determine how many prebunchers are to be used and to include two accelerating sections to accelerate the beam to about 26 MeV. Multibunch beam dynamic simulation results show that higher order mode couplers should be installed on each cell of TW buncher with the loaded quality factor of the dipole mode lower than 80.



TWB: 4 cells of phase velocity =0.75 c and 21 cells of phase velocity = c

E0=10 MV/m (at the input coupler of TW buncher), L2=0.8 m

For one 3 GHz prebuncher case: L0=50 cm, L1=40 cm

Figure 3: The schematic layout of the bunching system.

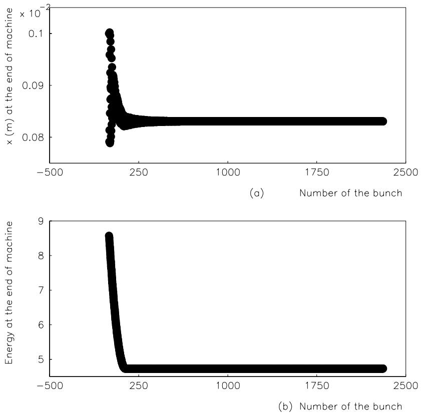


Figure 4: The bunch separation is 20 cm (final phase of CTF3), and the TW buncher is damped with $Q_{L,110} = 80$. At the exit of the TW buncher: (a) The transverse motion of a bunch train with an initial offset of 1 mm. (b) The energy gain of the bunch train.

5 ACKNOWLEDGEMENT

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6 REFERENCES

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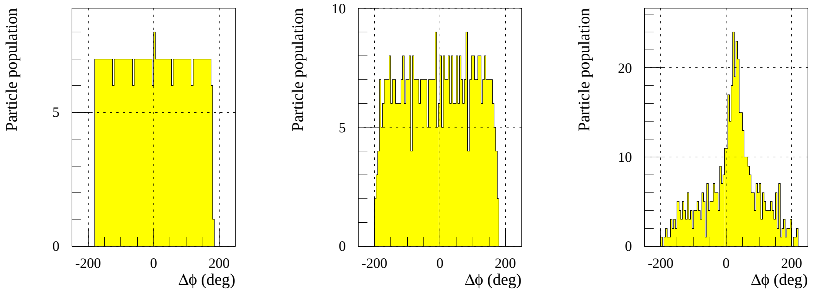
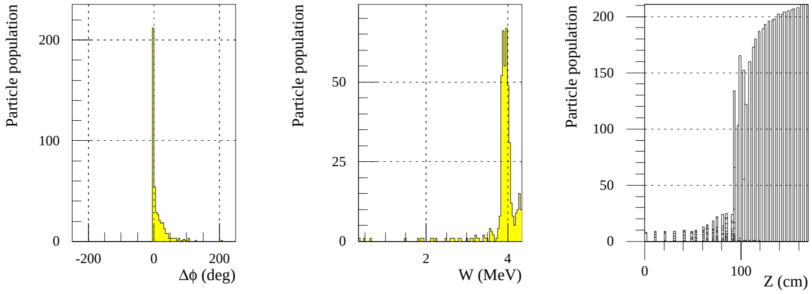


Cathode

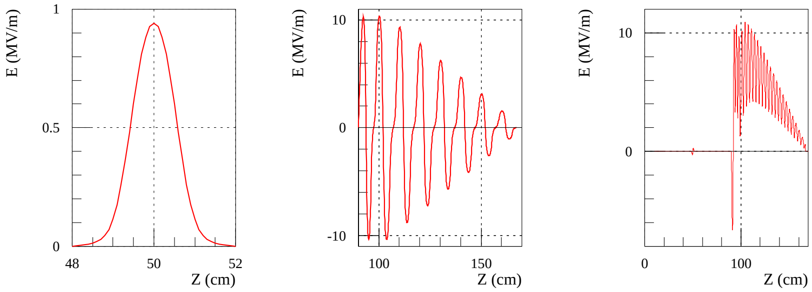
Entrance of the prebuncher

Entrance of the TW buncher



Exit of the TW buncher

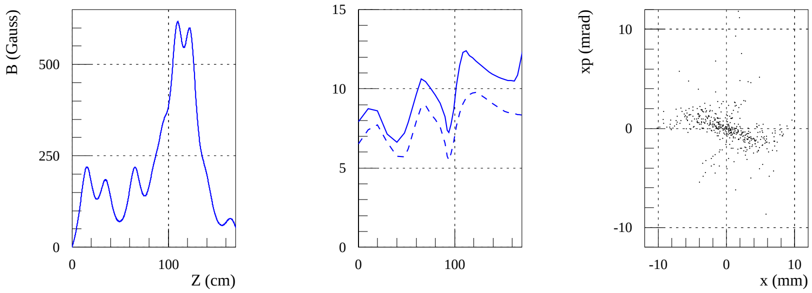
Exit of the TW buncher



E field in the prebuncher

E field in the TW buncher

E field felt by
the reference particle



B field

Beam envelope

Phase space at the
exit of the TW buncher

Figure 5: PARMELA simulation results.