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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 (bunch spacing is 10 cm) of CTF3 which consists of one (two) 3 GHz prebuncher(s) and one 3GHz travelling wave (TW) buncher with variable phase velocities ($\beta = 0.75$ and 1) working at $\frac{2\pi}{3}$ mode. 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 dimensions of the cavities in the two phase velocity regions are proposed. 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. 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 ourselves 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. In the following sections we will discuss the design of the travelling wave buncher considering the beam loading effect, the multibunch longitudinal and transverse beam dynamics in the TW buncher with the presence of long range wakefields, and the numerical simulations of the proposed bunching system by using PARMELA.

2 BEAM LOADING EFFECT

We start with the power diffusion equation in a linac

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

where $\alpha = \omega/(2Qv_g)$, v_g is the group velocity, Q is the quality factor, ω is the angular working frequency, $P(z)$ 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:

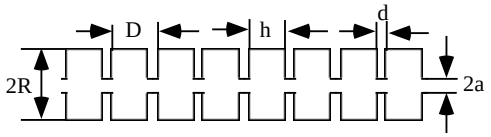

Figure 1: Disk-loaded accelerating structure

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

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} and α are kept constant within the accelerating structure, ϕ is the phase of the accelerating field ($\phi = \pi/2$ 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):

$$E(L) = 0 \tag{3}$$

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

$$P_0 = \frac{IE_0L}{2} \tag{4}$$

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:

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

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

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

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

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

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

where a, h, R, D, and d are defined in Fig. 1, $u_{01} = 2.405$, λ is the wavelength in free space, and θ_0 is the phase shift per cell. Now we make a rough design for the TW buncher working at 3 GHz (R$\approx$ 0.04 m) and $2\pi/3$ mode. If one takes $E_0 = 10$ MV/m, $I = 4$ A, $L = 0.8$ m, one finds

Cell type	D (m)	h (m)	a (m)	v_g/c
$\beta = 0.75$	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

$P_0 = 16$ 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.

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.

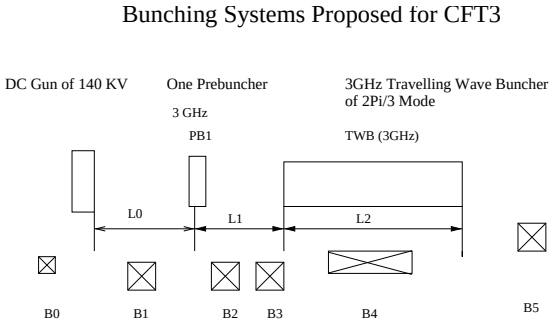

Figure 3: The schematic layout of the bunching system.

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 initial stage of CTF3 there is no need to damp the dipole modes in the TW buncher; however, for the final phase (bunch spacing is 20 cm) the dipole modes in the TW buncher have 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. Now we only show the simulation results in Fig. 5 for the single 3 GHz prebuncher case. The DC current coming from the cathode is 7 A and during 2π, 500 particles have been tracked. For the observing window of 20 degree centered around the bunch current peak, one gets 322 particles transmitted at the exit of the TW buncher,

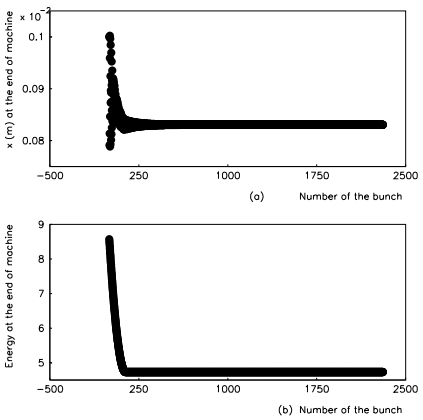

Figure 4: The bunch separation is 20 cm (final phase of CTF3), and the TW buncher is damped with $Q_{L,110} = 80$. At the exit of the TW buncher: (a) The transverse motion of a bunch train with an initial offset of 1 mm. (b) The energy gain of the bunch train.

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.

4 CONCLUSION

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 the loaded quality factors of the dipole modes in the TW buncher have to be lower than 80.

5 ACKNOWLEDGEMENT

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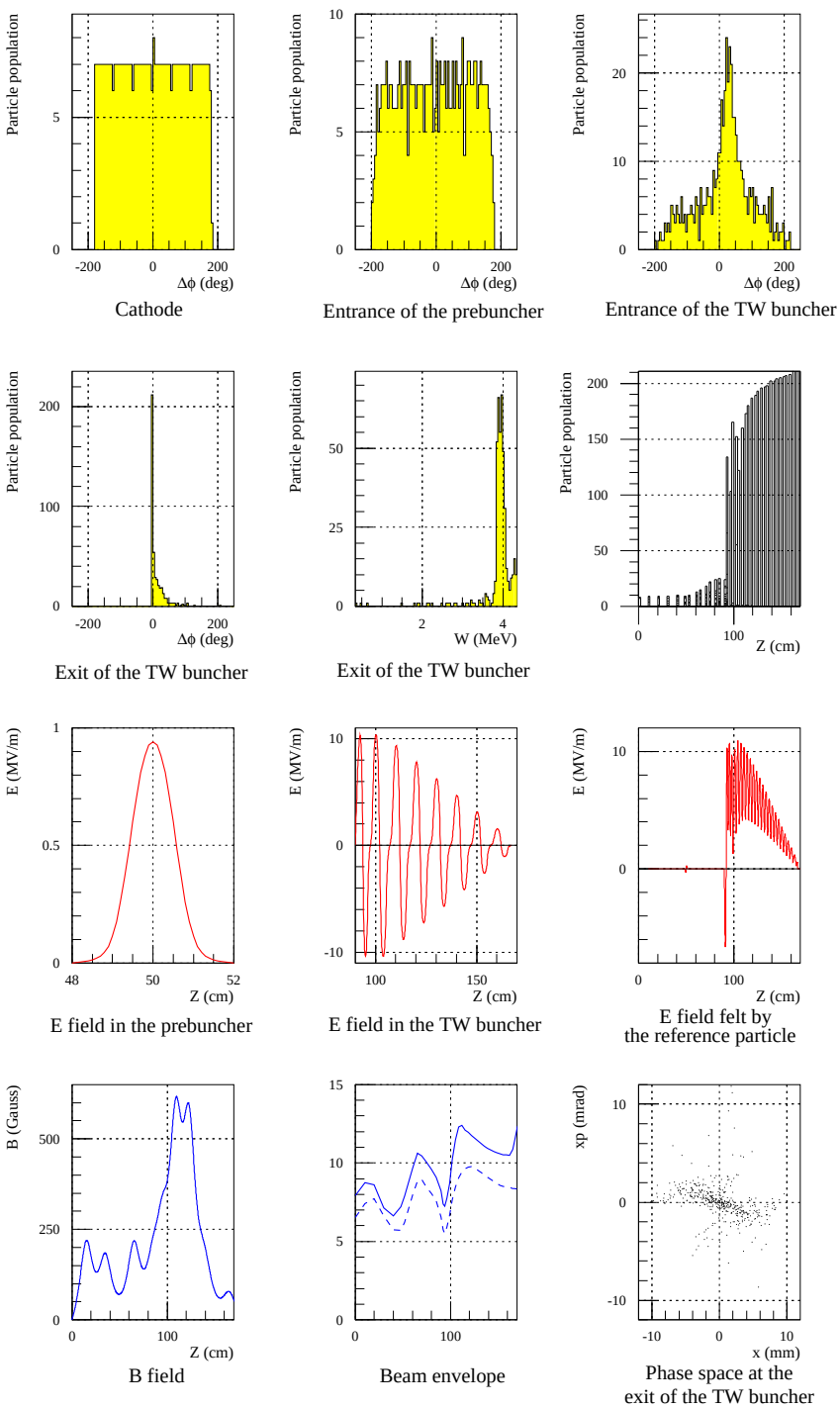

Figure 5: PARMELA simulation results.