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CTF3 DRIVE-BEAM INJECTOR DESIGN*

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Abstract

The Two-Beam Accelerator concept is one of the most promising methods for producing RF power for future linear colliders. In particular it allows upgrades to multi-TeV energies. One of its challenges is the production of the high current drive beam, which as it passes through decelerating structures, produces rf power for acceleration of the main beam. These challenges must be studied at a smaller scale test facility.

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The Two-Beam Accelerator concept is one of the most promising methods for producing RF power for future linear colliders. In particular it allows upgrades to multi-TeV energies. One of its challenges is the production of the high current drive beam, which as it passes through decelerating structures, produces rf power for acceleration of the main beam. These challenges must be studied at a smaller scale test facility.

1 INTRODUCTION

The purpose of the CLIC Test Facility 3 (CTF3) is to demonstrate the feasibility of the CLIC drive-beam bunch combination and acceleration scheme on a smaller scale, and the production of 30 GHz high-power rf [1]. This report describes the drive beam injector for CTF3. The bunch repetition rate is 1.5 GHz and 3.5 A of useable current is required at the end of the second accelerator section. The useable current is defined as the current due to the charge within 20° of the single bunch. The charge in the satellite bunches, one S-band cycle away, should be as low as possible.

2. THE INJECTOR

The injector, shown in figure 1, consists of a thermionic gun; three 1.5-GHz subharmonic bunchers; an S-band prebuncher; an S-band, tapered-phase-velocity, 17-cell, traveling-wave buncher; and two S-band, 1-m long, 34-cell, traveling-wave, accelerator sections. The transverse beam size control is accomplished with solenoids and the beam orbit is controlled with steering coils. Various diagnostics are used throughout the injector to aid in tuning and characterizing the electron beam from the injector. Simulation of the injector was conducted using EGUN for the gun, SUPERFISH and HFSS for the buncher and accelerator cavities, and PARMELA for the beam dynamics through the injector.

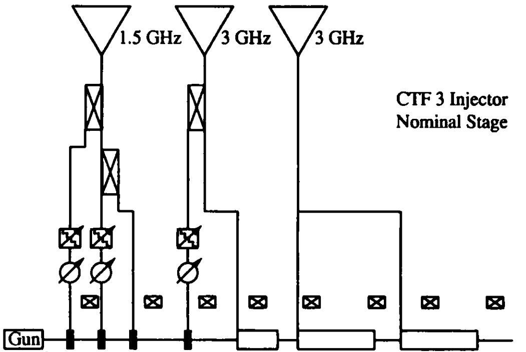

Figure 1. CTF3 injector block diagram.

3 THE ELECTRON GUN

The Thermionic electron gun for the CTF3 has Pierce type electrodes with a 2 cm^2 gridded cathode. The gun was designed for producing 9 A space charge limited current at 140 kV, which may be needed for very high-current running conditions. However, for nominal operation, the required current from the gun is 5 A according to the bunching and beam transport simulation results from PARMELA. The gun has been processed up to 160 kV at SLAC and delivered to CERN on a long term loan to be used on CTF3.

The gun electrode geometry and spacing was designed using EGUN. The electron beam parameters for the various stages of gun operation were calculated including the emittance due to geometric, thermal and grid-focusing effects. Figure 2 shows the EGUN ray trace for 5 A operation and table 1 lists the electron beam parameters for various types of gun operation.

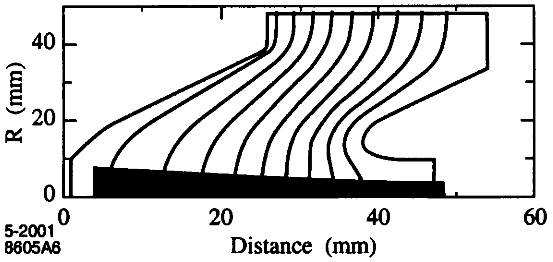

Figure 2. CTF3 gun ray trace from EGUN. 5 A, 140 kV grid limited mode.

Table 1. Electron Beam Parameters from the CTF3 gun.

Parameter	Unit	Grid limited		Space Ch. limited	
I	Amp	5	7	9.3	10.4
V	keV	140	140	140	150
$\varepsilon_{edge,N}$	mm-mrad	26	20	13	14

4 BUNCHING AND ACCELERATING STRUCTURES

The two S-band accelerator structures used in the injector are fully loaded and are described in reference [2,3]. The gap voltages in the standing wave prebunchers and the gradient in the traveling wave buncher were chosen to optimize bunching, keeping in mind the beam loading in these sections, as well as, the need to minimize the charge in the satellite S-band buckets. SUPERFISH was used to characterize the fields in these cavities, and produce space harmonics for the fields to be used in

PARMELA. Some of the limiting factors we imposed because of practical reasons were that the total available 1.5 GHz power should not exceed 700 kW and the S-band power available at the traveling wave buncher and the S-band power available for the accelerator sections would not exceed 35 MW. Table 2 shows the steady state gap voltage needed for bunching in the standing wave cavities after beam-loading compensation. Table 3 shows the traveling wave buncher parameters and gradients in each cavity after beam-loading compensation. The beam-loaded gradient in the first cavity of the accelerating sections is 11.4 MeV/m, tapering down until it is completely depleted toward the end of the structure.

Table 2. Effective gap voltage in the standing wave prebunchers with 5 A beam loading.

Buncher type	**Frequency** (GHz)	**Gap Voltage needed** (kV)	**Power in needed** (kW)
SHB 1	1.5	20	161
SHB 2	1.5	20	161
SHB 3	1.5	24	232
PB	3	52	in design

5 BEAM LINE SIMULATIONS

The Beam dynamics calculations were conducted using PARMELA with the beam parameters from EGUN and the cavity space harmonics from SUPERFISH as input. Special attention was given to maximizing the charge in a 20 degree longitudinal phase space and minimizing the charge in the S-band satellites. It is possible to reduce the charge in the satellite bunches by about a factor of two if a third type of buncher (4.5 GHz) is introduced after the 3 GHz prebuncher and this may be a future consideration.

Table 3. Effective gradient in the traveling wave buncher, with 5 A beam loading and 35 Mw input Power.

Cavity	Phase velocity β	Gradient (MV/m)
1	0.71	11.3
2	0.76	11.3
3	0.82	11.3
4	0.88	13.3
5	0.94	13.3
6	1.0	13.6
7	1.0	13.7
8	1.0	13.7
9	1.0	13.66
10	1.0	13.55
11	1.0	13.43
12	1.0	13.31
13	1.0	13.22
14	1.0	13.11
15	1.0	13.1
16	1.0	13.05
17	1.0	12.97

The longitudinal magnetic field to control the transverse size of the beam, starts at less than 1 Gauss at the cathode and ramps up to about 2 kGauss at the tapered phase velocity buncher where the beam is bunched, focused and accelerated. The solenoids were laid out avoiding interference with other beam-line components and groups of solenoids can be independently adjusted to control the electron-beam phase advance. Figure 3 shows the simulated magnetic field and emittance profile along the injector.

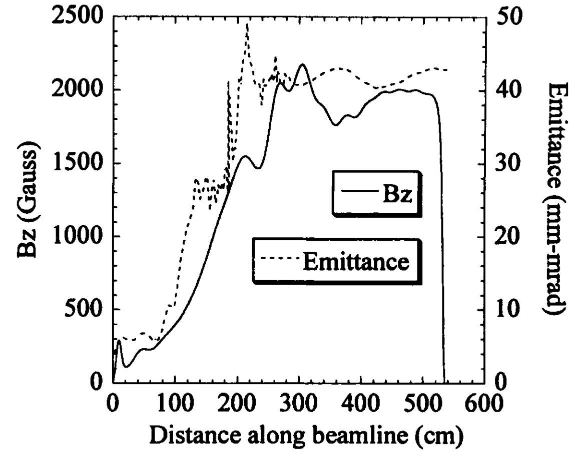

Figure 3. The longitudinal magnetic field and the beam transverse, normalized, rms emittance along the CTF3 injector. X = 0 is at the anode tip.

Given the above magnetic field, the beam envelope is well within the apertures, as shown in Figure 4.

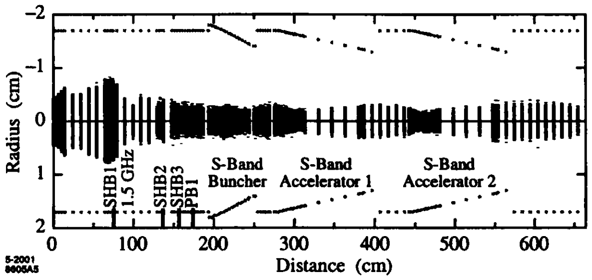

Figure 4. The beam envelope in the injector, based on simulations with PARMELA

Simulation results show that, given a 5.1 A beam from the gun, it is possible to capture 3.5 A in the main bunch, based on the charge in 20° of S-band. At the end of the second accelerating structure the beam energy is 19 MeV. The normalized rms emittance including all the beam at the end of the second accelerator structure is less than 50 mm – mrad. The bunch length is 12° at the FWHM, and the uncorrelated energy spread is about 200 KeV, about 0.1% of the final linac energy. If the beam is accelerated at the crest then the FWHM energy spread due to the 12° FWHM bunch length will be 0.5%. The capture into 20° longitudinal phase space is about 72% of the available charge at the end of the second accelerator structure, and the charge in 20° of the S-band satellite is about 8% of the charge in 20° of the main bunch. The total current accelerated to the end of the second section is about 4.9 A based on the simulations which do not take into account any orbit deviations from the centerline. In practice, the very low energy particles in the tail are expected to be lost before the end of the traveling wave buncher and the current in the first and second accelerator sections is expected to be about 4.5 A, in which case the current due to the charge in 20° of the main bunch will be about 78% of the total available current. The single-bunch beam parameters at the end of the second accelerator structure are shown in Figure 5 and tabulated in table 4.

5 SUMMARY

The CTF3 injector has been designed using realistic components and strengths. Currently we are in the process of the engineering design and construction of the individual components. Ample diagnostics to tune and measure the electron beam parameters in the injector have been planned and are in the process of being designed and prototyped. The integrated beam line assembly drawing with the realistic component dimensions is developing as the component drawings become available.

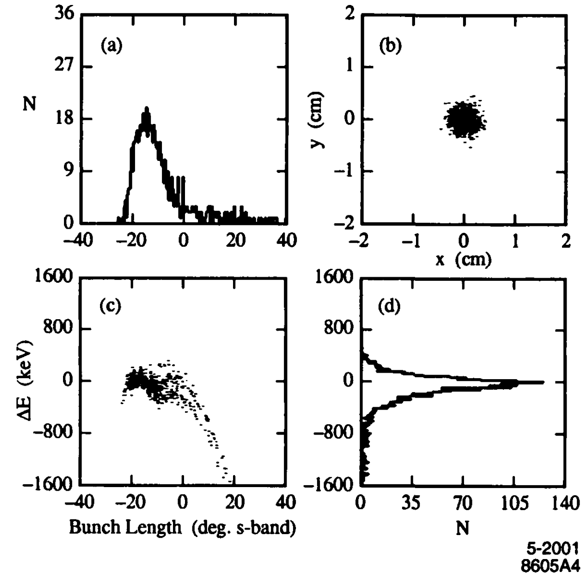

Figure 5. The simulated single bunch beam parameters at the end of the second accelerator section for the CTF3.
a) bunch current profile, b) bunch transverse distribution, c) bunch longitudinal distribution, d) bunch energy spread profile.

Table 4. CTF3 drive-beam injector target and simulated parameters.

Parameters	**Unit**	**Target**	**Simulated**
Beam Energy	MeV	≥ 20	19
Beam Current	A	3.5	3.5
Charge per Bunch	nC	2.33	2.33
Charge in Satellite	%	< 7	8
Bunch length FWHM	ps	< 12	12
Emittance N, rms	10^{-6} m	< 100	50
ΔE single bun. rms	MeV	< 0.5	0.5

6 REFERENCES

[1] R. Corsini, et. al., “An Overview of the New CLIC Test Facility (CTF3)”, CERN/PS 2001-030 (AE), proceedings of PAC01, Chicago, IL, 2001

[2] G. Carron, et. al., “Design of a 3 GHz Accelerator Structure for the CLIC Test Facility CTF (3) Drive Beam”, Proc. of LINAC2000, Monterey CA, 2000

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