Proceedings of the 1992 Linear Accelerator Conference, Ottawa, Ontario, Canada

BEAM DYNAMICS SIMULATIONS IN THE PHOTO-CATHODE RF GUN FOR THE CLIC TEST FACILITY

P. Marchand, Paul Scherrer Institute, CH-5232 Villigen, Switzerland
L. Rinolfi, CERN, European Laboratory for Particle Physics, CH-1211 Geneva 23, Switzerland.

Abstract

The CERN CLIC Test Facility (CTF) uses an RF gun with a laser driven photo-cathode in order to generate electron pulses of high charge ($\geq$10 nC) and short duration ($\leq$20 ps). The RF gun consists of a 3 GHz 1+1/2 cell cavity based on the design originally proposed at BNL which minimises the non-linearities in the transverse fields. The beam dynamics in the cavity is simulated by means of the "multiparticle tracking" code PARMELA. The results are compared to previous simulations as well as to the first experimental data.

Introduction

Studies are in progress for a CERN Linear Collider (CLIC), composed of a main linac and a drive linac. The latter which generates the 30 GHz RF power for the main linac requires high beam charges and short pulses. A CLIC Test Facility (CTF) was installed and brought into operation in 1991, with the following main goals: generation of high density electron bunches and production of 30 GHz RF power to test CLIC structures. The first objective is based on the use of a 3 GHz RF gun where a CsI photo-cathode is illuminated with an Nd:YLF laser.

First simulations were carried out with the "particle-in-cell" code TBCI-SF [1]. Here, beam dynamics simulations are performed with the "multiparticle tracking" code PARMELA and compared with the previous ones. Following the experience gained from experiments and the simulation results, a proposal is made for a set of working parameters which fulfil the CTF requirements.

CTF RF Gun Parameters

The CTF RF gun which is shown in Fig. 1 consists of a 1 + 1/2 cell cavity operated in a TM_{010}-π mode tuned at 2.99855 GHz. In Fig. 2, the fundamental RF field along the axis, computed with the SUPERFISH code, is plotted and compared to a sinusoid of wavelength λ = 10 cm. The deviations of the computed field from the ideal sinusoidal wave are mainly due to a cell length slightly too large for the 3 GHz frequency and field leakages into the beam pipe. We verified that, for typical CTF working conditions, both types of field distributions led to similar results. The main gun dimensions and computed RF characteristics are listed in Table 1.

Comparison of Simulation Results

Results of simulations from PARMELA and TBCI-SF are presented in Fig. 3. The main beam characteristics at the gun exit, γ, energy spread, bunch length and normalised emittance+ are plotted versus Φ_0 which is the RF phase at the time the electron bunch centre leaves the photo-cathode.

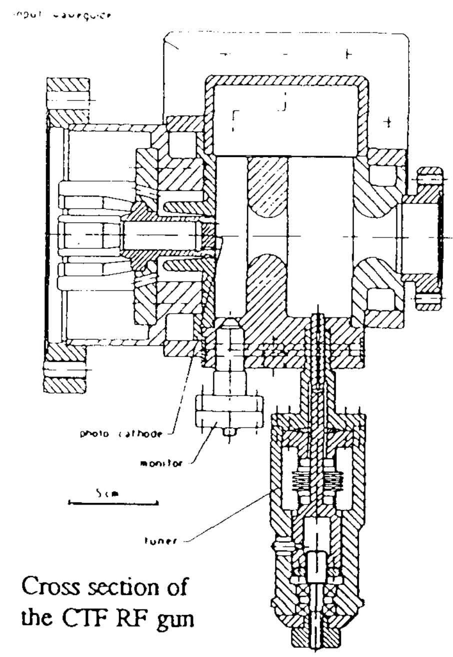

Fig. 1 Cross section of the CTF RF gun

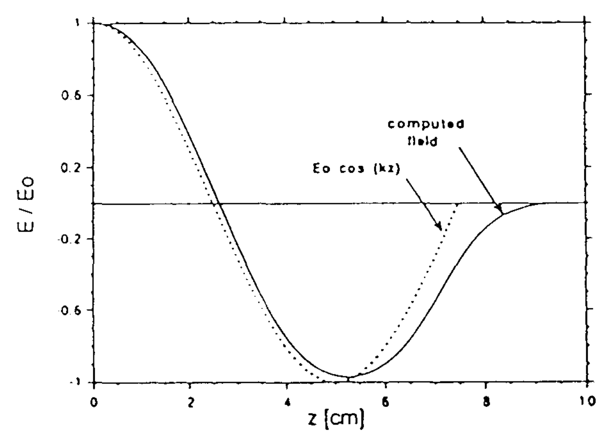

Fig. 2 On-axis electric field distribution in the RF gun

TABLE 1
RF Gun Characteristics (SUPERFISH)

1st (1/2) Cell Length	(cm)	2.63
2nd Cell Length	(cm)	5.195
Cell Radius	(cm)	3.96
Iris Aperture Radius	(cm)	1.0
Frequency (π-mode)	(MHz)	3003.6
Q		12,600
R_{shunt}	(MΩ)	1.6
E_{max}/E_0		1.06
RF Power (@ 100 MV/m)	(MW)	5.5
f_π - f_0	(MHz)	2.0

+ The normalised rms emittance is defined as follows:

$$\varepsilon_n = \beta\gamma \sqrt{<r^2><r'^2> - <r\,r'>^2}$$

The results from [1], reported here, have been adjusted according to this Φ_o definition. PARMELA used the electric field distribution, computed from SUPERFISH. The other input parameters involved in the simulation are listed in Table 2.

TABLE 2

Input Parameters used in the Simulations

	TBCI-SF (1991)	PARMELA (1992)
Emitted charge	$Q_o = 9.4$ nC	$Q_o = 10$ nC
Laser pulse length	Δt_o (HWHM) = 10 ps (parabolic)	$\sigma_{to} = 8$ ps (gaussian)
Peak current	$\hat{I}_o = 470$ A	$\hat{I}_o = 500$ A
Laser spot size	$r_o = 5$ mm (uniform)	$\sigma_{ro} = 3$ mm (gaussian)
Current density*	$J_o = 600 \text{A/cm}^2$	$\hat{J}_o = 880 \text{ A/cm}^2$
$^*\hat{J}_o = Q_o/\left(\sqrt{2\pi}\,\sigma_{to}\, 2\pi\, \sigma_{ro}^2\right)$		

For these equivalent sets of initial conditions and a maximum field E_o of 100 MV/m at the photo-cathode, a good agreement is found between the results obtained from the two different computer codes. PARMELA also confirmed TBCI-SF predictions [2] that at this field level, the space charge effects were still significant along the transfer line downstream of the gun. Details of all simulations are reported in [3].

Working Point Φ_o

Figure 3c shows that the bunch length compression increases as Φ_o becomes smaller. It was also found that the charge transfer efficiency Q_f/Q_o essentially remains constant within a Φ_o range from 18° to 50°; for lower Φ_o, it drops rapidly since the particles at the head of the bunch experience negative field and then are pulled back onto the photo-cathode. At both field levels, the maximum peak current is thus obtained when Φ_o = 18°. Moreover, for E_o = 60 MV/m, it coincides with the maximum energy gain and minimum energy spread. For E_o = 100 MV/m, maximum energy gain and minimum energy spread are found around 45°. The characteristics of both working points are compared in Table 3.

It is interesting to note that, at low Φ_o, the longitudinal phase space distributions are quite linear and therefore well suited for a further magnetic compression.

TABLE 3

Comparison of 2 Working Points for Φ_o

E_o	Φ_o	E_c	σ_E	σ_Z	Q_f/Q_o	$\hat{I}$	ε_n
MV/m	deg	MeV	%	mm	%	A	mm. mrad
100	45	4.1	0.8	1.9	99	626	53
100	18	3.8	1.5	1.3	99	950	63
60	45	2.4	3.7	2.3	87	450	67
60	18	2.4	1.5	1.5	85	680	63

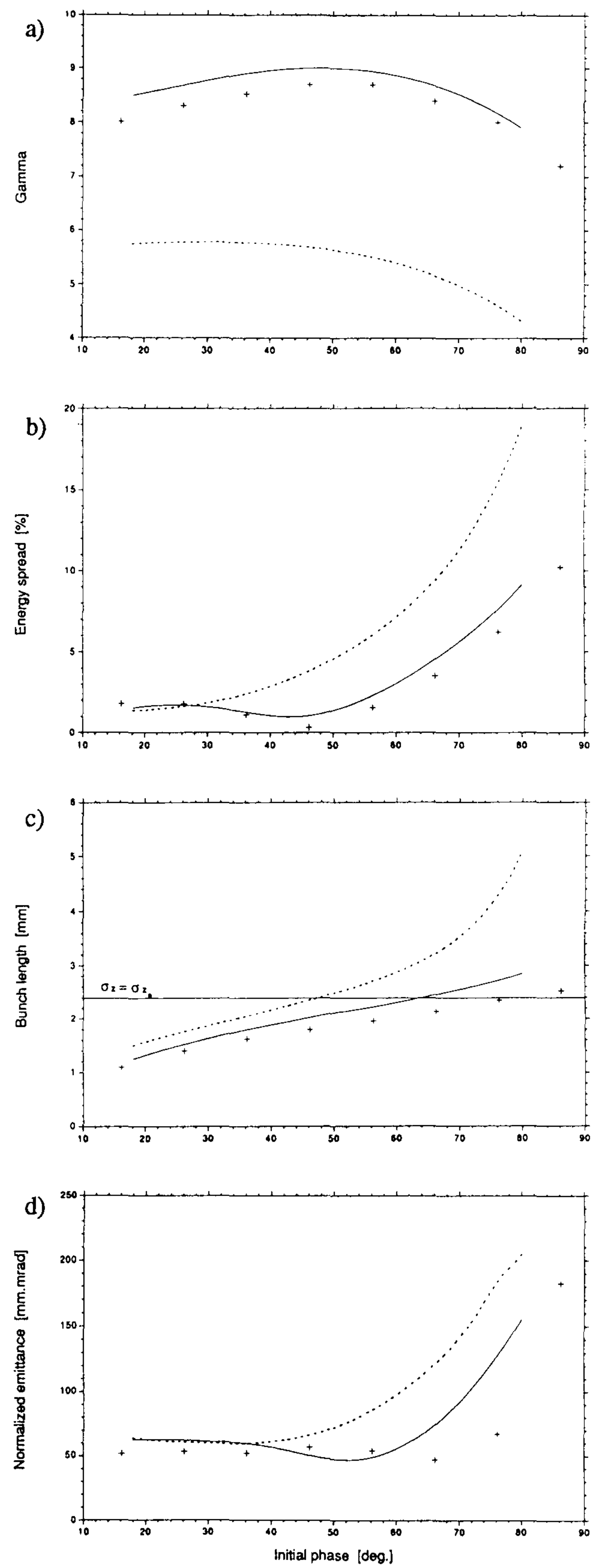

Fig. 3 Beam characteristics at the gun exit
- - - - E_o = 60 MV/m (PARMELA)
—— E_o = 100 MV/m (PARMELA)
+ E_o = 100 MV/m (TBCI-SF) [1]

CTF Requirements and Present Status

Providing for the nominal power of 48 MW in the CLIC accelerating structure typically requires at the gun exit, 8 bunches of charge $Q = 11$ nC and length $\sigma_z = 1.5$ mm ($\sigma_t = 5$ ps) [4].

During experiments in 1991 with a CsI photo-cathode, the gun was routinely operated around 70 MV/m without RF breakdowns. The beam energy of 2.7 MeV measured in these conditions is close to the computed value of 2.8 MeV. From the preceding simulation results, one can anticipate that, at this field level, the beam characteristics $Q_o = 12$ nC, $\sigma_{ro} = 3$ mm, $\sigma_{zo} = 2.4$ mm ($\sigma_{to} = 8$ ps) and an initial phase set around 20° should approximately fulfil the requirements.

Pulse lengths σ_{to} from 5 to 8 ps and spot sizes $\sigma_{ro} \approx 3$ mm were obtained from the Nd:YLF laser which was recently installed in the CTF. At this wavelength, a 2% quantum efficiency was measured from the CsI photo-cathode. By splitting the total available laser energy of 120 µJ, it should therefore be possible to produce the required charge in the 8 bunches. The proposed operating conditions and expected beam characteristics (PARMELA) are summarised in Table 4. Figure 4 shows the corresponding computed phase space distributions at the gun exit.

TABLE 4
Typical CTF operating conditions

Laser micro pulse		
Wavelength	λ_ℓ (nm)	209
Energy	E_ℓ (µJ)	4
Spot size	σ_{ro} (mm)	3
Duration	σ_{to} (ps)	8
Nb of micropulses	n_p	8
Photo-cathode		
Quantum efficiency	QE (%)	2
Emitted charge	Q_o (nC)	12
Peak current density	$\hat{J}_o$ (A/cm^2)	1060
Diameter	d (mm)	8
RF gun		
Max. cathode E field	E_o (MV/m)	70
Initial phase	ϕ_o (deg)	20
RF power	P_{rf} (MW)	2.7
Bunch at the gun exit		
Kinetic energy	E_c (Mev)	2.8
Energy dispersion	σ_E (%)	0.7
Length	σ_z (mm)	1.5
Size	σ_r (mm)	4.8
Charge	Q_f (nC)	11
Peak current	$\hat{I}$ (A)	880
Norm. emittance	ε_n (mm.mrad)	53
Divergence	$\sigma_{r'}$ (mrad)	34
Number of bunches	n_b	8

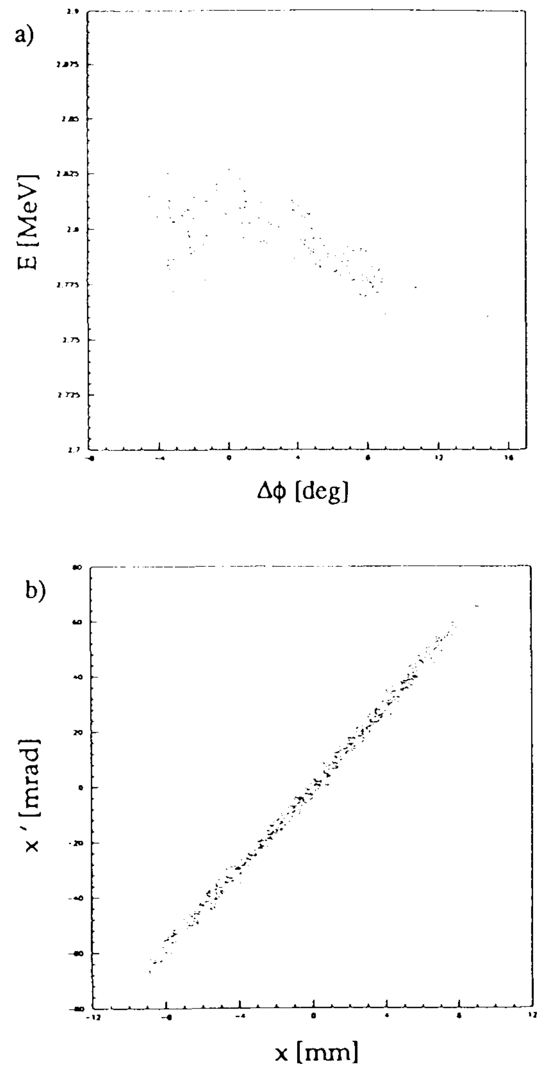

Fig. 4 Longitudinal (a) and transverse (b) phase spaces

Conclusion

Beam dynamic simulations of the CTF gun were performed with two different programs: TBCI-SF and PARMELA. Although the latter does not take into account the wake field effects, both programs lead to similar results. By simulating operating conditions based on the first experimental results and the expected performance from the Nd:YLF laser which was recently installed, it was found that the CTF requirements can theoretically be fulfilled. Further experiments and simulations (transfer line downstream of the gun, efficient splitting and transport of the optical power, possibility of increasing the number of cavity cells, ..) are under way.

Acknowledgements

We would like to thank W. Remmer for the installation of PARMELA and other facilities on the CERN CRAY computers.

References

[1] H. Kugler et al.,EPAC90, Nice (1990), p. 709-711.
[2] J. Strõde, PS/LP Note 91-28.
[3] P. Marchand, L. Rinolfi, PS/LP Note 92-19.
[4] J.P. Delahaye, CERN PS 92-44 (LP).