BEAM DYNAMICS FOR THE CLIC TEST FACILITY

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Abstract

The CERN Linear Collider (CLIC) requires two beams: the main and the drive beam. The latter will consist of bunches of high charge and short pulse length in order to get the 80 MV/m (average) accelerating gradient at 30 GHz. The CLIC Test Facility (CTF) was brought into service in 1991 with the main objective to study the drive beam generation.

Here we present the beam dynamics simulations for the different CTF configurations implemented from 1993 up to now. Simulations are mainly done with the code PARMELA. Special attention has been given to space charge and transverse wake field effects, which are the main limitations for the CTF. The simulation results are compared with the experimental results.

Introduction

In 1993, the CTF was mainly composed of an RF gun (4 MeV), a long travelling-wave section (60 MeV), a CLIC structure where the 30 GHz RF power is generated and a probe beam to check acceleration with another 30 GHz CLIC structure [1]. In 1994, a new 4 cell standing wave cavity (booster) was added which raises the beam energy to 11 MeV before the travelling wave section [2]. A second klystron was installed and feeds the RF gun and the booster. The first one connected to the travelling-wave section allows to raise energy up to 80 MeV. Recently the design of a magnetic bunch compressor at 11 MeV has been finalised [3]. It will be implemented in 1995. All PARMELA simulations are performed for a single bunch and comparison with single bunch measurements characterise the CTF performance at high charges. However the 30 GHz power generation is obtained from a bunch train, at lower charge, and simulations for wake fields are performed accordingly.

CTF line in 1993

The simplified 1993 CTF layout is shown in Fig. 1 except that the booster, the bunch compressor and the 4 quadrupoles (Q1 to Q4) were not installed. The quadrupole triplet at the exit of the LAS matches the beam emittances to the entrance of TRS (4 mm diameter iris). Several simulations have been performed with TRANSPORT and PARMELA codes [1]. The RF gun was modelled with PARMELA code, but also MAFIA code was extensively used [4]. Without space charge effect and at low charge, both codes gave the same results. However discrepancies appeared at high charge.

The initial phase is defined as the phase where the centre of laser pulse hits the photo-cathode minus the phase of RF voltage when it is zero on the photo-cathode. This latter was 12 mm in diameter. The optics was made in such a way that almost all the photo-cathode was illuminated. However the transverse distribution was not measured and for simulations, both Gaussian and uniform distributions were used. Table 1 gives a comparison, for a charge of 10 nC, between PARMELA simulations and experimental results..

TABLE 1
Simulation and Experimental Data for 1993

		Simul.	Exper.
Laser pulse at the gun			
Spot size	σ_{ro} (mm)	3	
	Total (mm)	12	10
Duration	σ_{to} (ps)	3.8	
	FWHH (ps)	9	9
Photo-cathode			
Emitted charge	Q_o (nC)	10	10
RF gun			
Max. cathode E field	E_o (MV/m)	100	100
Initial phase	ϕ_o (deg)	45	45
RF power	P_{rf} (MW)	5.85	6
Bunch at the TRS			
Momentum	p (MeV/c)	57.9	58
Energy dispersion	σ_E (%)	1.8	2
Length	σ_z (mm)	1.86	
	FWHH (ps)	14.6	15
Transverse size	σ_x(mm)	1.8	0.9
	σ_y(mm)	1.6	
Divergence	$\sigma_{r'}$ (mrad)	1.3	
Charge	Q_f (nC)	8.2	7.4
Norm. rms emittance	ε_x	428	150
(mm.mrad)	ε_y	417	

σ_x and ε_x have been measured at 3 nC. The experimental results were consistent with the simulation results although it was not possible to compare all parameters with high charge.

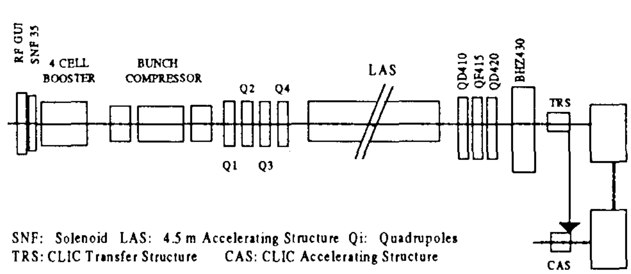

Fig. 1 CTF line in 1995

CTF line in 1994

The simplified 1994 CTF layout is shown in Fig. 1 except that the bunch compressor and the 4 quadrupoles (Q1 to Q4) are not yet installed and are replaced by one solenoid. The booster allows the minimisation of the space charge effects at low energy. PARMELA simulations are reported in Table 2 for a charge of 2.8 nC and compared to the experimental results. The laser pulse and the photo-cathode are identical to those in 1993.

TABLE 2
Simulation and Experimental Data for 1994

		Sim.	Exp.
RF gun			
Max. cathode E field	E_0 (MV/m)	100	100
Initial phase	ϕ_0 (deg)	45	20 - 50
RF power	P_{rf} (MW)	5.85	6
Booster			
Electric field on axis	E (MV/m)	70	70
Phase	$\varnothing$ (deg)	90	90
Bunch at the TRS			
Momentum	p (MeV/c)	81.8	80
Energy dispersion	σ_E (%)	0.4	< 0.2
Length	σ_z (mm)	1.	1.1
	FWHH (ps)	8	9
Transverse size	σ_x(mm)	0.2	0.5
	σ_y(mm)	0.4	0.5
Divergence	$\sigma_{x'}$ (mrad)	1.2	
Charge	Q_f (nC)	2.8	2.8
Norm. rms emittance	ε_x	42	39
(mm.mrad)	ε_y	40	

The measured horizontal emittance is scaled from FWHH measurements. Finally there is a good agreement between PARMELA simulations and experimental results for a single bunch at the charge value used with the bunch train. The peak performance, for a single bunch, is 23 nC at the booster exit, 16 nC at the LAS exit and 7 nC downstream of TRS. The peak performances, for power generation, achieved today, are the following:

Bunch train	24 bunches
e- pulse length (FWHH)	8 ps
charge at TRS input	2.8 nC/bunch
30 GHz power at TRS	60 MW (peak)
Peak electric field in TRS on axis	110 MV/m
Average electric field in TRS	79 MV/m
Peak Electric field in CAS on axis	103 MV/m
Average electric field in CAS	73 MV/m

In the present layout the most serious limitation for 30 GHz power production is given by transverse wake field effects. To estimate the magnitude of these effects the transverse wake potentials of the booster, the LAS and the CLIC structure were computed with the code ABCI [5] and the results were put in a self made tracking program for multibunch wakefield effects. The resulting emittance growth of a train of 24 bunches with 2.8 nC bunch charge is shown (Fig. 2). Note the fast growth in the 30 GHz structure. However, the computed growth is not sufficient to explain the observed effects, since it accounts for only one fifth of the total emittance (cf. table 2). This discrepancy could maybe explained by the fact that contributions of the RF gun are not included in the calculations. The wake potential concept cannot be applied there due to the large change of particle velocity over one cell. Also the contributions of discontinuities in the vacuum chamber, like pumping ports, and of RF input/output couplers are not included, since ABCI is limited to axially symmetric structures.

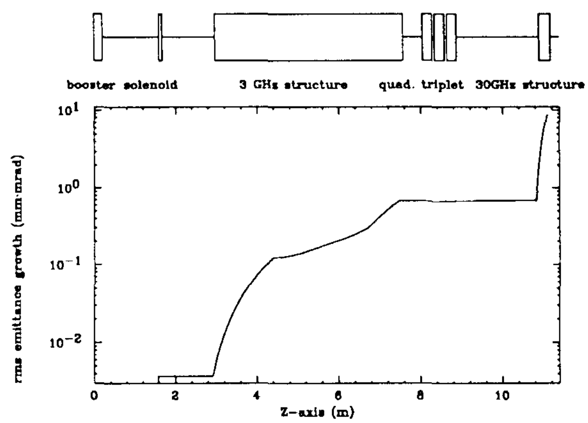

Fig. 2 Emittance growth from booster to TRS due to transverse wake fields.

CTF line in 1995

The main limitations in the present CTF are the space charge effects at low energy and the wakefields in the long accelerating structure. In order to minimise the first effects, the photo-cathode will be illuminated with a longer laser pulse ($\sigma = 8$ ps) and downstream of the booster, bunches will be compressed down to the required pulse length ($\sigma \leq 3$ ps). This compression will be achieved using off crest acceleration in the gun and a 3 dipole magnetic chicane (Fig. 1). Quadrupoles Q1 to Q4 will match the beam at the input of LAS. The installation of an RF pulse compressor is foreseen for LAS. The higher gradient will lower the energy spread due to beam loading. Simulations were performed to study the CTF beam dynamics [3] for charges varying between 0 and 10 nC. The optimisation is done in order to get a good transmission up and through the CLIC Transfer Structure (TRS). The bunch compressor is designed for an energy up to 20 MeV. Additionally, a spectrometer line has also been designed and will be implemented after the first dipole.

The solenoid is optimised in order to get a convergent beam at the entrance of the bunch compressor to compensate the divergence of the beam induced by the gun. The phase of the gun and the booster are chosen to get a good correlation between the phase and the momentum of the bunch such that the energy spread is maximum. Particles in the front of the bunch have a lower momentum than the ones in the tail. This correlation is obtained by moving the beam from the crest of the RF where the energy spread is minimum to a phase where the RF slope is large. The resulting energy spread is 3.6% for a beam extent of 13° at 10 nC at the entrance of the bunch compressor. The transmission efficiency is kept at its maximum from the RF gun to TRS.
Figures 3 and 4 show the longitudinal phase space before and after compression. The beam extents in phase are respectively 13° and 3.2° corresponding to 3.6 mm and 0.88 mm, i.e. the compression factor is 4.

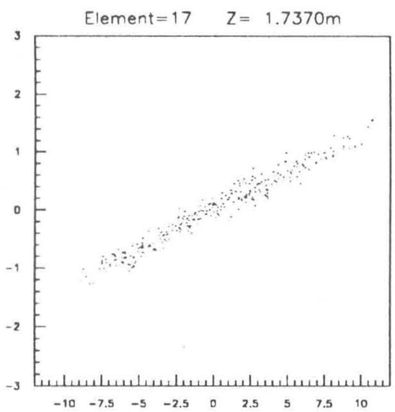

Fig. 3 Longitudinal phase space for 10 nC, before compression.

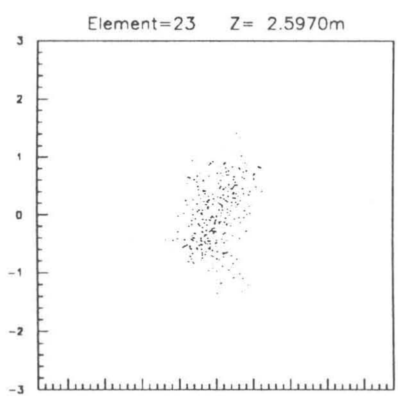

Fig. 4 Longitudinal phase space for 10 nC, after compression.

Table 3 presents the simulation results from PARMELA.

TABLE 3
PARMELA Output Data for 10 nC

Momentum: P [MeV/c]	
at the exit of the gun:	4.5
at the exit of the booster	11
at the exit of the bunch compressor	11
at the entrance of TRS	80
Momentum spread: $\delta p/p$ [%]	
at the exit of the gun:	1.6
at the exit of the booster	3.6
at the exit of the bunch compressor	2.6
at the entrance of TRS	1.1
RMS transverse sizes [mm]	
at the exit of the gun:	x=y=4.5
at the exit of the booster	x=y=4.7
at the exit of the bunch compressor	x=4.5, y=1.0
at the entrance of TRS	x=1.4, y=1.3
RMS transverse divergences [mrad]]	
at the exit of the gun:	x'=y'=31.
at the exit of the booster	x'=y'=70.
at the exit of the bunch compressor	x'=2.0, y'=6.8
at the entrance of TRS	x'=0.7, y'=0.6
RMS norm. emittances [mm.mrad]	
at the exit of the gun:	$\varepsilon_x=\varepsilon_y=64.$
at the exit of the booster	$\varepsilon_x=\varepsilon_y=70.$
at the exit of the bunch compressor	$\varepsilon_x=132$, $\varepsilon_y=60$
at the entrance of TRS	$\varepsilon_x=177$, $\varepsilon_y=130$

Conclusion

With the different simulations performed on the CTF, giving a rather good agreement with the experiments, it is now possible to understand better the present limitations and therefore to take action to reach the CLIC figures for the high charges and the drive beam generation.

Acknowledgement

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References

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