BEAM DYNAMICS SIMULATIONS FOR CLIC DRIVE BEAM ACCELERATOR*

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Abstract

CLIC study aims at a center-of-mass energy for electron-positron collisions of 3TeV using room temperature accelerating structures at high frequency (12 GHz) which are likely to achieve 100 MV/m gradient. Due to conventional high frequency RF sources do not provide sufficient RF power for 100 MV/m gradient, CLIC relies upon a two-beam-acceleration concept: The 12 GHz RF power is generated by a high current electron beam (Drive Beam) running parallel to the main beam with deceleration in special Power Extraction Structures (PETS) and the generated RF power is transferred to the main beam. In order to obtain very high RF power at 12 GHz frequency, injected beam into PETS should have 2.37 GeV energy, 101 A pulse current and pulse length around 240 ns. Drive beam accelerator (DBA) accelerates the beam up to 2.37 GeV in almost fully-loaded structures and the pulse after DBA contains more than 70000 bunches, has a length around 140 μs and 4.2 A pulse current. After some modifications in delay loop and in combiner rings the beam has 101A pulse current and 240 ns pulse length. In this study simulations of some transverse beam parameters for different options for the lattice of the DBA are presented.

INTRODUCTION

Compact Linear Collider (CLIC) project is a study for a future electron-positron collider that would allow physicists to explore a new energy region beyond the capabilities of today's particle accelerators . Within the framework of a world-wide collaboration on Linear Colliders, CLIC study aims at a center-of-mass energy range for electron-positron collisions of 0.5 to 5 TeV, optimised for a nominal center-of-mass energy of 3 TeV [1]. In order to reach this energies CLIC proposes to use a two-beam-acceleration concept: The 12 GHz RF power is generated by a high current electron beam (drive beam) running parallel to the main beam. This drive beam is decelerated in special power extraction structures (PETS) and the generated RF power is transfered to the main beam and obtainable gradient is up to 100 MV/m [2].

In order to produce high-frequency (12 GHz) for high gradient acceleration short RF pulses of high peak power are typically required. As a result of the present optimization of the accelerating structure 240 ns long pulses at about 64 MW per accelerating structure are needed for CLIC [2]. To produce these pulses, the CLIC concept is based on the power source schema given with Fig. 1, in which an electron beam (the drive beam) is accelerated using standard, low-frequency RF sources and then used to produce RF power at high frequency.

Drive-Beam linac, which are normal conducting accelerators travelling wave cavities operate at 999.5 MHz, accelerate bunches up to 2.4 GeV with long pulses (140 s) and 60 cm bunch seperatrion; the bunch distances in the long pulse are manipulated using delay loop, combiner ring-1 and combiner ring-2 and bunch seperation becomes 2.5 cm. With other words 4.1 A pulse current is increased by factor of 24 and becomes about 101 A.

In this study we only represent some simulations for acceleration section of drive beam for different lattice investigations using the PLACET code [3].

ACCELERATING STRUCTURE

Two types of structures have been studied [4] for accelerating the beam up to 2.38 GeV in DB linac: the "Tapered Damped Structure" (TDS), originally designed for the CLIC main accelerator and "Slotted Iris - Constant Aperture" (SICA) structure which was successfully built and tested at 3 GHz and have been implemented as DBA structures for CTF3. A TDS scaled to 999.5 MHz would however be very large (outer diameter 1.3 m) and SICA structures would have an outer diameter of approximately 520 mm at 999.5 MHz therfore we only take into account SCIA structure in our calculations.

For SICA structure operate at 999.5 MHz, each of 33 regular cells will constitute an accelerating structure and that has approximately 3.75 m length. With an input power of 33 MW, calculated RF-to-beam efficiency is about 93% for such a structure with the nominal 4.21 A beam current. For the full beam loading operation acceleration gradient is 7.3 MV, thus the requirement of 326 accelerating structures to achieve the drive beam energy of 2.38 GeV [2].

The long-range transverse wakefield is represented by the lowest two dipole modes of each cell. The damping of the lowest dipole mode has been considered $Q = 11$ for each cell although first and last cell has different parametes. For second dipole band we have used $Q = 400$ as it was done for CTF3 [4]. The short-range longitudinal wake fields were not taken into accont while transverse wakefields have been calculated and are included in the simulation.

* Work supported by Turkish Atomic Energy Authority
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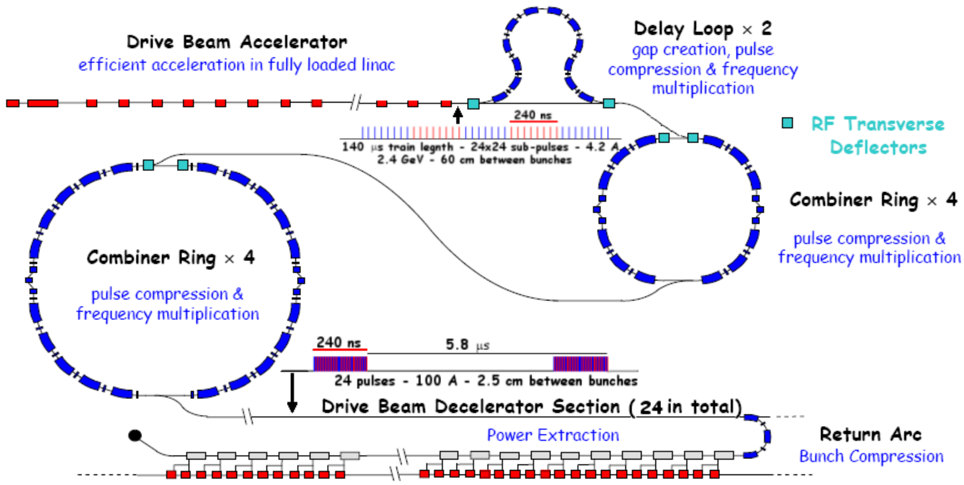

Figure 1: Schematic layout of one CLIC RF power source complex.

LATTICES

We have used FODO and triplet lattice types which each lattice cell houses four accelerating structure. The length of both lattic cells are about 17 meter see Fig 2 and Fig. 3

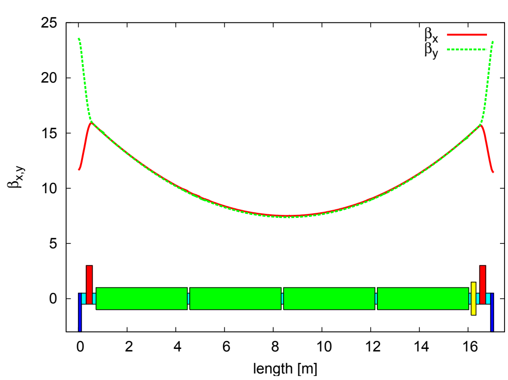

Figure 2: Beta functions in a cell of the triplet lattice and sketch of a single triplet cell.

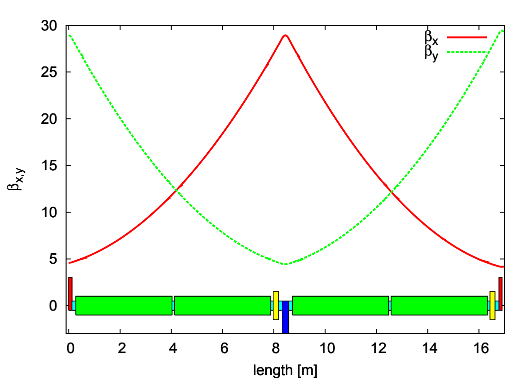

Figure 3: Beta functions in a cell of the FODO lattice and sketch of a single FODO cell.

For the calculations of triplet lattice, the length of the accelerating structures is assumed to be 3.75 m and four structures are placed between triples (Fig. 2 green colored) and the length of the quadrupoles is assumed to be 25 cm (Fig. 2 red and blue colored). A 20 cm distance has been foreseen for additional elements, and the spacing between the quadrupoles in the triplet is 20 cm. Between triplet and structures 15 cm additional spaces has been foreseen. In the FODO lattice two structures are placed between each pair of quadrupoles. This leads to a cell length about 17, the same as in the triplet lattice. Same distances are foreseen for additional elements as it is at triplet cell.

The relative strengths of these quadrupoles with respect to the central one have been determined so that one obtains a round beam in the structures. The strengths of quadruploes for triplet and FODO lattice is given in Table 1.

Table 1: Quadrupole Parameters for Triplet and FODO Lattices

TRIPLET LATTICE	Qfoc	Qdef
Effective length (cm)	25	25
Srength m^{-1}	1.85256	-3.60691
μ_x $(^0)$	97.11	
μ_y $(^0)$	96.65	
FODO LATTICE	Qfoc	Qdef
Effective length (cm)	25	25
Srength m^{-1}	0.7	-0.7
μ_x $(^0)$	93.38	
μ_y $(^0)$	93.38	

The transverse wakefields were derived by scaling the ones calculated for CTF3 with respect to the frequency. The emittance has been tracked through the perfectly aligned linac using PLACET. Figure 4 shows the emittance for single bunch and multi bunch in a pulse along the linac for triplet and FODO lattice.

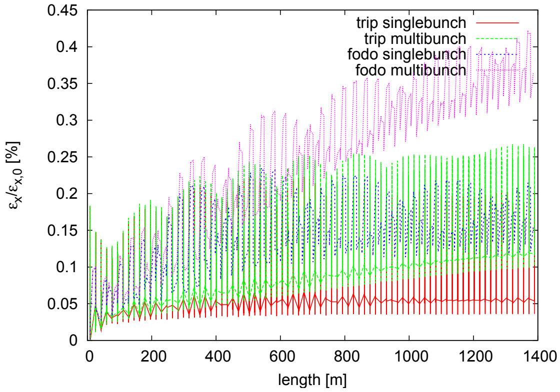

Figure 4: Emittance variation along the linac for triplet and FODO lattice.

Figure 5 shows longitudinal phase plot for perfectly aligned machine. Although we have used same gradient for accelerator structure energy gain for triplet lattice is more than FODO.

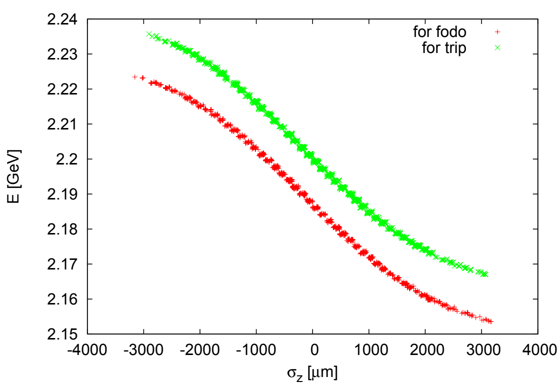

Figure 5: Longitudinal phase space of a bunch at the exit of accelerating structure.

The effect of a transverse jitter of the initial beam is shown in Figure 6. The beam is offset by (Δx, Δy) 2% initial beamsizeat the linac entrance, tracked through the linac and the final offset is plotted for both triplet and FODO lattices. As it is clearly seen the train for FODO lattice have significantly larger amplitudes than the train for triplet lattice.

CONCLUSION

This preliminary simulation study is just a simple calculations for CLIC Drive-Beam accelerator and has been done for single bunch and short short pulses. For nearest future different lattice types with different quadrupole strengths will be taken into account. The assumed transverse and longitudinal wakefields of the SCIA structure will be calculated in details and corrected. Afterwards we propose to simulate whole pulse and define transverse kick factors and acceptance limitations in order to find out optimum lattice type with optimum cost consideration. We also propose to study the matching from the injector to the linac and from the linac to the delay loop for all lattices. Although TDS structure does not seem realistic because of its diameter size for 1 GHz we also plan to make same calculations using same lattice sketchs. We aim to achive desired beam parameters which are given in Table 2.

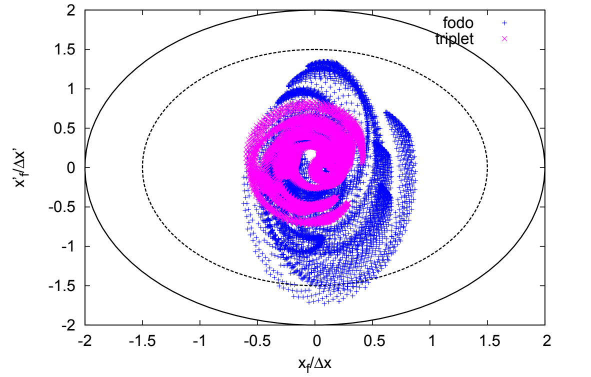

Figure 6: The amplifiaction factor of the beam at the end of the drive-beam accelerator, using the FODO and triplet lattice. Δx and $\Delta x'$ is initial beam offset of the beam; x_f and x'_f final beam coordinates.

Table 2: Desired Beam Parameters of CLIC Drive-Beam

Parameter	Unit	Value
Initial Beam Eenergy	(MeV)	50
Final Beam Eenergy	(GeV)	2.38
Bunch Charge	(pC)	8.4
Pulse length	(μs)	140
Rms Bunch Length	(mm)	4
Normalised emittance	(mm.mrad)	100
Number of bunches/pulse		70128
RMS Energy Spread	(%)	1

REFERENCES

[1] M. Battaglia, A. de Roeck, J. Ellis, D. Schulte (editors), “Physics at the CLIC Multi-TeV Linear Collider”, CERN report 2004-005, hep-ph/0412251

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[3] https://savannah.cern.ch/projects/placet/

[4] G. Carron et al., “Design of a 3 GHz Accelerator Structure for the CLIC Test Facility (CTF3) Drive Beam,” Linac 2000, TUA16, CLIC Note 451 (2000).

[5] D. Schulte, “Beam Dynamics Simulation for The CTF3 Drive-Beam Accelerator”, arXiv:physics/0008131v1,2000.