A MULTI-DRIVE BEAM SCHEME FOR TWO-BEAM ACCELERATION IN A TEV LINEAR COLLIDER

R. Corsini, J.P. Delahaye. C. Johnson, A. Millich, A. Riche,
CERN, CH 1211 Geneva 23, Switzerland

Abstract

The Compact Linear Collider (CLIC) study of an e+/e- linear collider in the TeV energy range is based on Two-Beam Acceleration (TBA) in which the overall RF power needed to accelerate the beam is extracted from high intensity relativistic electron beams, the so-called drive beams. Due to the high beam power, acceleration and transport of the drive beams in an efficient and reliable way is specially challenging. An overview of a potentially effective scheme is presented. It is based on the generation of trains of short bunches, accelerated in low frequency c.w. superconducting cavities, stored in an isochronous ring and combined at high energy by funneling before injection by sectors into the drive linac.
The various systems of the complex are discussed as well as the beam dynamics all along the process. An original method has been specially developed to stabilize such an intense beam during deceleration and RF power production in the drive linac.

1 INTRODUCTION

The 65 MW of RF power at 30 GHz for e+/e- acceleration up to 1 TeV c.m. in CLIC [1] is provided by high-current relativistic electron beams (the drive beams). The conversion of drive beam energy into RF power is made by means of low impedance resonant structures (CLIC transfer structures, CTS). The power is then fed into the accelerating structures (CLIC accelerating structures, CAS) of the two main linacs (e+/e-), running in parallel with the drive linacs.

Each one of the two drive linacs is divided in 10 sections of ~ 600 m length, powered by different drive beam pulses, providing 136 GW of peak power for 50 GeV acceleration of the main beam. The main and drive linacs are composed of many short modules, whose layout is depicted in Fig. 1.

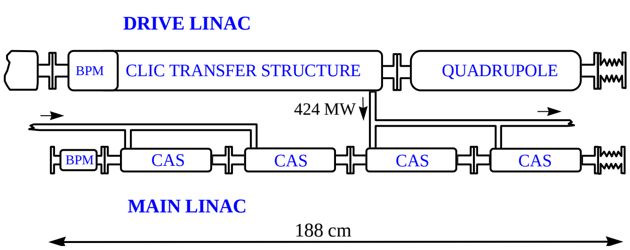

Figure 1. Main-drive linac module.

In such scheme one CTS feeds four CLIC accelerating structures (CAS). In this paper the following set of CAS and CTS parameters are considered:

		CTS	CAS	
R/Q	=	100 Ω/m	25 kΩ/m	shunt impedance
l	=	1.33 m	0.39 m	effective length
Q	=	4750	3500	quality factor
v_G	=	0.41 c	0.065 c	group velocity

With the given parameters the required peak RF power per CAS is 106 MW, and the pulse duration is 50 ns. The RF pulse is generated in the CTS by a drive beam pulse composed of 560 bunches, spaced by 3 cm.

The total charge per pulse is 5.6 μC, with a charge per bunch increasing from 5.3 nC to 11.4 nC in the first 20 ns and staying constant for the rest of the pulse, in order to obtain the desired RF pulse shape for beam loading compensation of the main beam. The CTS is a traveling wave structure composed of a cylindrical chamber of 10 mm radius coupled by longitudinal slits to four teeth-loaded rectangular waveguides.

The structure has been optimised [2] using the code MAFIA, in such a way as to obtain the desired coupling and group velocity, while keeping the transverse wakefields to a minimum level (~ 1 V/pC/mm/m). In order to control the transverse instability of the drive beam during RF power production, damping of the dipole mode is foreseen by slits located at 45° in the chamber and terminated with loads.

2 DRIVE BEAM GENERATION

Several schemes for the CLIC drive beam generation are at present under study [3,4]. In the solution described here [5], short bunch trains are generated using photocathode rf guns, accelerated in superconducting structures and then combined with the correct spacing. In this way the global beam loading is distributed in time over all the repetition period, allowing its compensation by power refill of the accelerating structures. A long collector ring (20 km) is used to store the bunches as they are accelerated. The bunches are compressed to their final length only after extraction from the ring. In this way the isochronicity requirements are relaxed, and the resistive wall effect in the ring is minimised. A smaller ring (the combiner ring) is used for the final recombination of the bunches at the right spacing.

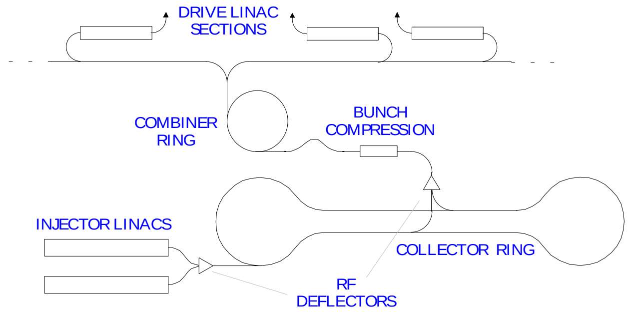

Figure 2. Drive beam generation complex layout.

In Fig. 2 a schematic layout of the drive beam generation complex is depicted. Initially, 2 × 160 trains composed of 35 bunches each are generated in two photoinjectors and accelerated up to 1.8 GeV in two 612.5 MHz superconducting linacs in push-pull configuration. The bunches in a train are spaced by 48 cm and have an rms length of 5 mm. This is repeated with the repetition rate of the main linac (700 Hz). A total of 1.83 GV of cavities at fundamental plus 45 MV cavities at 612.5 MHz ± ε to provide beam loading compensation along the train will be installed. The train to train beam loading is compensated by power refilling of the structures in between the passage of the 160 trains. The necessary RF power at 612.5 MHz is 70 MW, the power per meter of structure being 390 kW/m.

The trains are then combined two by two using a transverse RF deflector at the same frequency as the linacs, halving the distance between bunchlets. The trains are then injected into the collector ring using simple magnetic kickers. The ring is of dog-bone shape, and the two long straight sections (~ 10 km each) can be located in the same tunnel as the main and drive beam.

The end bends are composed of two 360° arcs with the same radius (125 m) needed for the main beam bends, and could be in the same tunnels as well.

After 1.4 ms the whole ring will be filled. When the last train is injected, the ring is emptied. Every second train is ejected by magnetic kickers in two different locations of the ring, at 10 km distance, and each train couple is recombined in a transverse RF deflector operating at 612.5 MHz.

The bunches are then compressed in length by RF (170 MV, 2.5 GHz, superconducting) + magnetic chicanes down to an rms length of 0.6 mm.

The trains are combined four by four in the combiner ring (270 m long), in order to obtain 20 trains of 560 bunches at 3 cm distance. The injection into the ring is made using two transverse RF deflectors at 2.5 GHz that creates a time dependent local deformation of the equilibrium orbit [6]. When all of the four trains are combined, they are extracted by a magnetic kicker, and the whole cycle is repeated for the next four. The 20 long trains so obtained are alternately switched in the two drive linacs.

The longitudinal beam dynamics has been evaluated all along the drive beam generation complex, in order to ensure that the final parameters (bunch length and energy spread) will allow the beam transport and power production in the drive linacs.

The longitudinal wakes and RF curvature in the injector linac, the radiation losses, the resistive wall effect, the space charge and the non-isochronicity in the collector ring are included in the calculation.

The rms energy spread along each bunch train after beam loading correction is very small (~ $6 \cdot 10^{-4}$). The single bunch energy spread at the exit of the injector linac is determined by the combined effect of the longitudinal wakefields and of the RF curvature and is of the level of 0.26 %.

In order to minimize the phase errors between bunchlets introduced in the magnetic chicane by the energy fluctuations between bunchlets, a 180° two-stage compression system is planned to be used [7]. In such a case, the phase error between bunches in a train can be kept to less than ± 1 degree. The final bunch length is 0.6 ± 0.02 mm rms as desired, while the total energy spread is limited to 6 %, which appears to be acceptable for transport to the drive linac.

3 THE DRIVE LINAC

The drive beam must be transported along the drive linac keeping the losses to a minimum, since even a small fraction of the drive beam power can give rise to an unacceptable local temperature increase [8].

The problem is complicated by the huge energy spread that the drive beam bunches develop along the linac (the first bunches of the train remain approximately at the 1.8 GeV injection energy, while the last bunches reach a minimum energy of ~ 200 MeV, see Fig. 3) and by the transverse wakefields in the CTSs. The drive beam focusing is based on variable strength FODO cells.

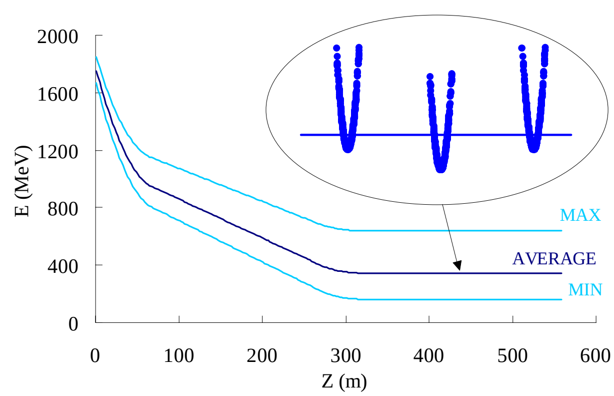

Figure 3. Energy profile along a drive beam pulse at the end of a drive linac section. The energy distribution within three subsequent bunches of the steady state part is also shown.

The initial quadrupole gradient is decreased along each linac section as the bulk of the drive beam pulse loses energy, thus keeping the full energy range in the stable region of betatron phase advance.

In order to control the transverse beam break-up, a certain amount of damping of the dipole mode in the CTS is necessary. On top of that, a novel method [9] (tuned decoherence damping, TDD) has been devised to control the instability during deceleration. An energy modulation is introduced in the train in such a way that odd bunches have a few percent energy difference with respect to the even bunches, as shown in Fig. 3. This essentially decreases the instability growth rate by damping coherent oscillations between adjacent bunches. The lattice parameters and the TDD amount can be optimised depending on the beam parameters using simulation codes that include the wakefields, specially developed for this purpose [9, 10]. In the case considered here, an energy difference of about 5 % is the optimum value; it could be introduced in the drive beam before injection using 40 MV of 5 GHz cavities.

The results of a typical simulation are shown in Fig. 4. Without wakefields (100% structure damping), the beam envelope is controlled all along the section and explodes afterward when the FODO becomes unstable for the lowest energy part of the beam. In the case of no or insufficient CTS damping, the transverse wakefield instability arises very soon, while the use of 30% damping of the dipole mode between subsequent bunches (100 ps) and of decoherence damping allows the instability to be controlled up to the end of the section.

The CTS rms misalignment is assumed to be 50 μm in this simulation, while the rms quadrupoles misalignment is 5 μm. Such values can in principle be obtained by applying a beam based one-to-one alignment algorithm to a witness drive beam pulse, but assumes a very good stability (< 5 μm) of the quadrupole magnetic center.

The use of a dispersion-free algorithm for the drive linac prealignment has been investigated, and while it gives better results for the trajectories without wakes, the simulation results including wakefields show a bigger beam blow-up. Studies on pre-alignment methods that can relax the required precision and improve the operability are under way.

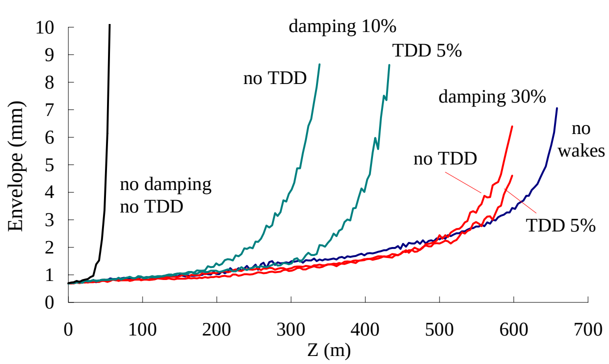

Figure 4. Drive beam envelope along a drive linac section for different hypothesis. The initial integrated quadrupole strength is 5 T, decreasing to a final value of 0.6 T at the end of the section (600 m).

4 CONCLUSIONS

A method has been described for the generation of the CLIC drive beam based on recombination of bunch trains at high energy. Such a method could provide a very good efficiency of ~ 40% (wall plug to RF) for 30 GHz power production. In spite of the unusually high power, the drive beam generation and acceleration are pretty conventional. The splitting in sections of the drive linac allows to keep the power in each drive beam at the acceptable value of 7 MW and makes the scheme easily extendable. The main drawbacks are the necessary gymnastics in beam storage and combination, and the relatively high CTS impedance, resulting in an increased transverse instability. As can be seen in Fig. 4, the drive beam stability is on the edge of the wakefield limit, and a critical issue will be the amount of damping which can be introduced in the CTS.

Experimental tests with beam are under way in the CLIC Test Facility, equipped with modules similar to the ones depicted in Fig. 1, although the CTS and drive beam parameters are somewhat different.

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