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Beam dynamics design of the Compact Linear Collider Drive Beam injector

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ABSTRACT

In the Compact Linear Collider (CLIC) the RF power for the acceleration of the Main Beam is extracted from a high-current Drive Beam that runs parallel to the main linac. The longitudinal and transverse beam dynamics of the Drive Beam injector has been studied in detail and optimized. The injector consists of a thermionic gun followed by a bunching system, some accelerating structures, and a magnetic chicane. The bunching system contains three sub-harmonic bunchers, a prebuncher, and a traveling wave buncher all embedded in a solenoidal magnetic field. The main characteristic of the Drive Beam injector is the phase coding process done by the sub-harmonic bunching system operating at half the acceleration frequency. This process is essential for the frequency multiplication of the Drive Beam. During the phase coding process the unwanted satellite bunches are produced that adversely affects the machine power efficiency. The main challenge is to reduce the population of particles in the satellite bunches in the presence of strong space-charge forces due to the high beam current. The simulation of the beam dynamics has been carried out with PARMELA with the goal of optimizing the injector performance compared to the existing model studied for the Conceptual Design Report (CDR). The emphasis of the optimization was on decreasing the satellite population, the beam loss in the magnetic chicane and limiting the beam emittance growth in transverse plane.

1. Introduction

The Compact Linear Collider (CLIC) is a future multi-TeV electron-positron collider under study at CERN. A TeV-range accelerator at a reasonable size and cost requires a very high acceleration gradient which was set to 100 MV/m in this case. In a classic approach, the RF power would be provided by klystrons. However, about 35,000 high power klystrons (50 MW) would be needed and this large number of klystrons is not feasible in terms of cost and maintenance [1]. In the CLIC acceleration scheme, the RF power for the acceleration of the Main Beam is extracted from a high-current Drive Beam that runs parallel to the main linac. The Drive Beam loses its energy in special RF structures (decelerators) called Power Extraction and Transfer Structures or PETS. Such a Drive Beam scheme is also more power efficient than the standard klystron powering because as explained in Section 2, the Drive Beam is generated and accelerated with low frequency high-efficiency klystrons. This Drive beam then goes through a frequency multiplication process. The two beam acceleration scheme of CLIC is shown in Fig. 1 [1].

The main feasibility issues of the two-beam acceleration scheme are being demonstrated at CLIC Test Facility 3 (CTF3) which is a small-scale version of CLIC [2]. The main points should be demonstrated at CTF3 are the efficient generation of the Drive Beam and the RF power production [1].

In the next sections we first introduce the phase coding process and the concept of satellite and then the Drive Beam injector and its longitudinal and transverse design is described. The beam dynamics simulations represented in this paper have been carried out with PARMELA [3] and the results are compared with the previous model studied for the CDR [1].

2. Drive Beam time profile

Fig. 2 illustrates the Drive Beam time structure at the end of Drive Beam Accelerator (DBA). The main pulse consists of 24 bunch trains of 244 ns length. The distance between successive bunch trains is 5.8 μs (24×244 ns). Each bunch train contains 2922 bunches with a repetition frequency of 12 GHz.

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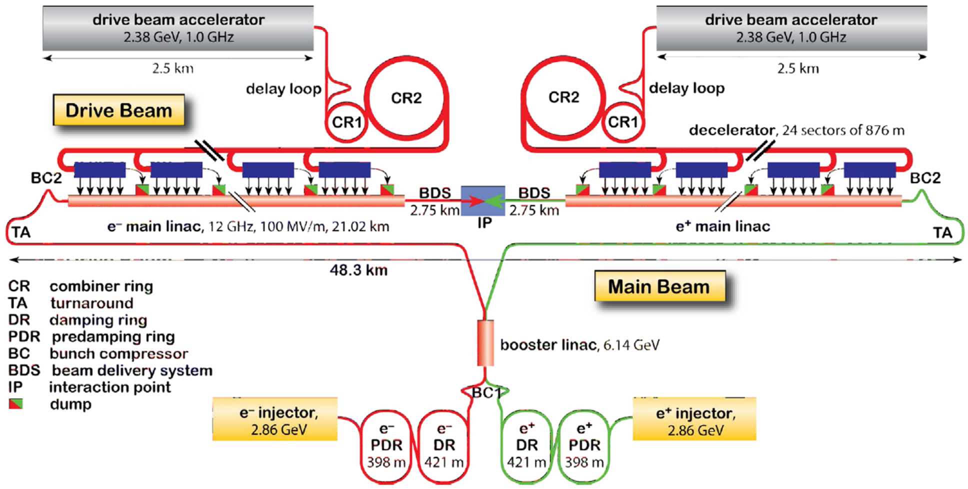

Fig. 1. CLIC layout (not to scale). The main beams are generated and pre-accelerated at the center of the complex and along with the Drive Beam is transported to the low energy part of the linac. The power of the Drive Beam is extracted and transferred to the main beam via the decelerators.

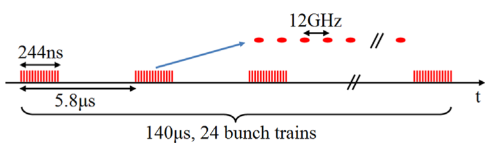

Fig. 2. Drive Beam final time structure at the end of DBA.

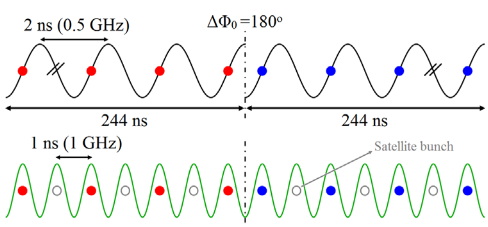

Fig. 3. Schematic illustration of the phase coding process and satellite production.

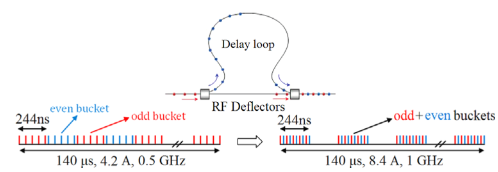

Fig. 4. Bunch train combination principle in the delay loop. The phase coded trains are essential for the operation of the delay loop.

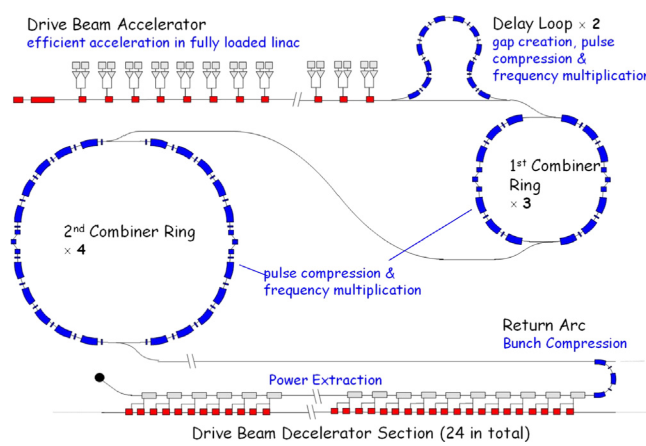

Fig. 5. Drive Beam full complex (not to scale).

To achieve such a time structure the continuous beam from the electron gun passes through the 0.5 GHz sub-harmonic bunching system. This system changes its phase by 180° every 244 ns – the length of each bunch train. After the sub-harmonic bunching system, a 1 GHz prebuncher and buncher are used to reduce the bunch length, then the beam is accelerated in 1 GHz traveling wave structures. Therefore, as illustrated in Fig. 3 only every second accelerator bucket is occupied. Due to the phase switching of the sub-harmonic bunching system the main pulse is made up of even and odd bunch trains. This procedure is called phase coding. However, in a real system a few percent of particles are captured in wrong buckets, called satellite bunches.

According to Fig. 4, at the end of DBA, a delay loop with two RF deflectors is used to direct the even and odd bunch trains into a loop or a straight path. By choosing the correct flight time, the bunches of the delayed train will be replaced between the bunches of the following train. Therefore, the combined train will have twice the bunch repetition frequency and twice the current [1].

After the delay loop, in a similar procedure, the bunch trains are recombined three and four times in the following two combiner rings (see Fig. 5). Therefore, the overall multiplication of the frequency would be 24 and we will achieve the target time structure needed (Fig. 2). The bunch repetition frequency increases from 500 MHz to 12 GHz and the current from 4.2 A to 101 A. The full Drive Beam complex is shown in Fig. 5 [1].

If the satellite bunches are not removed from the beam they are going to be lost at the entrance of delay loop causing unwanted radiation. On the other hand this reduces the machine power efficiency because of the acceleration of the unwanted bunches in fully loaded structures. Therefore, a satellite cleaning system is proposed to be located at the end of Drive Beam injector [1]. However, if the satellite population drops below a certain value we may not need to remove them.

3. Drive Beam injector

The performance of an accelerator is largely affected by the initial parameters of the beam provided by the injector. Due to the low velocity of the particles, the injector design involves the challenging problem of the space-charge effect especially for high-current accelerators. Apart from the interesting physics of the space-charge dynamics, the unique feature of the Drive Beam injector is dealing with the satellite concept that adversely affects a machine performance.