SUB-HARMONIC BUNCHING SYSTEM OF CLIC DRIVE BEAM INJECTOR

Sh. Sanaye Hajari[1, 2], S. H. Shaker[1, 2], S. Doebert[1],
[1]CERN, Geneva, Switzerland, [2]IPM, Tehran, Iran

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 with the main linac. The sub-harmonic bunching system of the drive beam injector has been studied in detail and optimized. The model consists of a thermionic gun, three travelling wave sub-harmonic bunchers followed by a tapered travelling wave buncher. The simulation of the beam dynamics has been carried out with PARMELA with the goal of optimizing the overall bunching process and in particular capturing particles as much as possible in the buncher acceptance and decreasing the satellite population.

INTRODUCTION

The Compact Linear Collider (CLIC) is the future Multi-TeV electron-positron collider under development at CERN. The main objective is to build a high-energy accelerator at a reasonable cost and size. This requires a very high acceleration gradient (100 MV/m). In a classic approach, the RF power would be provided by klystrons. However, the klystrons with the required pulse length are not available on market. On the other hand, about 35000 high power klystrons are needed. This large number of klystrons is not feasible in terms of cost and maintenance [1]. In the novel acceleration scheme of CLIC, the RF power for the acceleration of the Main Beam is extracted from a high-current Drive Beam that runs parallel with the main linac. The Drive Beam loses its energy in 'decelerator' in special RF structures, which are called Power Extraction and Transfer Structures (PETS).

DRIVE BEAM TIME PROFILE

At the end of the Drive Beam complex as shown in Fig. 1 the main pulse with the length of 140µs, consists of 24 bunch trains of 244ns length and each bunch trains contains 2922 bunches with a time separation corresponds to 12 GHz.

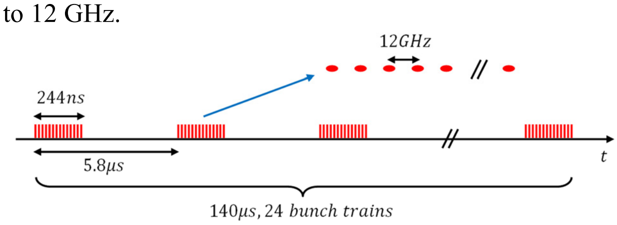


Figure 1: The final time structure of the Drive Beam.

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 switches its phase by 180° every 244ns.

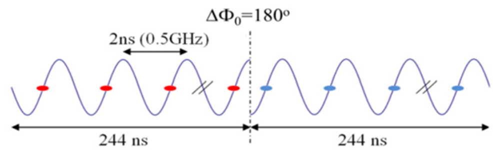


Figure 2: Phase switching.

After the sub-harmonic bunching system a 1 GHz travelling wave buncher is used to reduce the bunch length more and then the beam is accelerated with 1 GHz frequency. Therefore, only every second of RF bucket of the accelerator is occupied. Thanks to the phase switching of the sub-harmonic bunching system the main pulse is made up of even and odd bunch trains (see Fig. 3). This procedure is called phase coding.

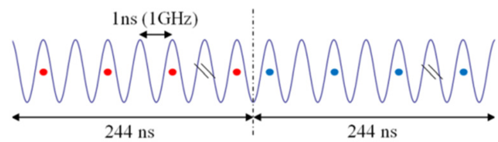


Figure 3: Phase coded Drive Beam.

Although in real system about 5% of particles captured in wrong buckets, called satellite bunches. These bunches have to be eliminated for reasons of efficiency and machine protection at the end of injector [1].

According to Fig. 4 a delay loop is used to combine even and odd trains to get twice the bunch repetition frequency and twice the peak current.

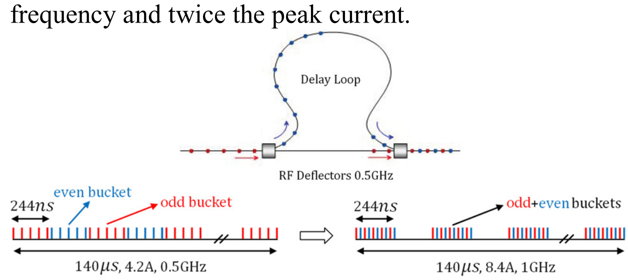


Figure 4: The principle of bunch combination in the delay loop [1].

In a roughly same procedure, the trains are recombined three and four times in the following two combiner rings. Therefore, the overall multiplication of the frequency and the peak current will be 24 and we will achieve the final time structure needed.

SUB-HARMONIC BUNCHING SYSTEM

General layout of the CLIC Drive Beam bunching system is shown in Fig. 5.

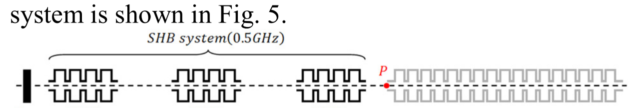


Figure 5: General layout of bunching system.

The sub-harmonic bunching system consists of three travelling wave sub-harmonic bunchers (SHB). This system has two functions. The first is to provide even and odd bunch trains and secondly to act as a prebuncher for the travelling wave buncher. This system should be optimized with the following optimization criteria.

- To maximize the population of the particles in the acceptance of the buncher (which is optimized to provide minimum bunch length).
- To minimize the population of satellite bunches.

The principle of bunching with sub-harmonic bunching system is based on velocity modulation bunching [2, 3]. The sub-harmonic bunching system is optimised in three stages. First, we ignore the effect of space charge and consider thin lens approximation for simplicity. Then the effect of space charge is considered and finally the realistic travelling wave structures are studied.

Thin Lens Approximation

In thin lens approximation the travelling wave structures is replaced with the simple thin lens cavities.

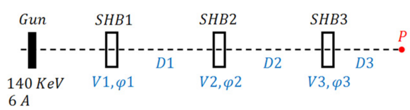


Figure 6: Thin lens approximation.

In this approximation one can easily track particles in longitudinal phase space using the following relations.
In a drift space:

$$\Delta\varphi = 360 fD/\beta c \qquad \Delta w = 0 \tag{1}$$

In a SHB:

$$\Delta\varphi = 0 \qquad \Delta w = eV\sin[\Phi_0 + \varphi - \varphi_r] \tag{2}$$

Where φ and w are the phase and the kinetic energy of particles. φ_r is the phase of the reference particle and Φ_0 is the phase of the RF field seen by that particle. After tracking we can count the percentage of particle in the buncher acceptance and the satellite population according to relations (3) and (4) respectively.

$$-60 \le \varphi_P \le 60 \tag{3}$$

$$-180 \le \varphi_P \le -90 \vee 90 \le \varphi_P \le 180 \tag{4}$$

The buncher acceptance is found to be [-60, 60] after inserting and optimizing the buncher.

For the optimization of the thin lens system a simple computer code is written with *MATHEMATICA* software which changes the phases and voltages of the cavities and also the drift spaces between them to fine the optimum configuration. Figure 7 shows the final longitudinal phase space and the phase spectrum of the beam at the entrance of the buncher. In this configuration 92.3% of particles are in the acceptance of buncher and the satellite population is 5.0%.

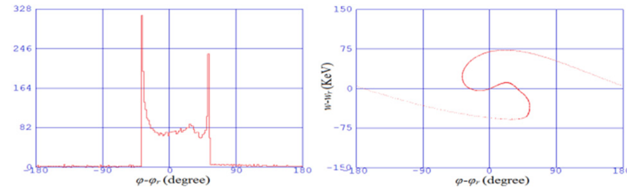


Figure 7: The final phase spectrum (left diagram) and longitudinal phase space (right diagram) of the beam at the entrance of the buncher (ignoring the space charge).

The Space Charge Effect

The effect of the space charge forces is investigated in various configuration of the system. The disturbing effects of the space charge on longitudinal beam profile start when the phase spectrum becomes very narrow. In This situation particles are longitudinally close together. This mostly occurs in the first drift section.

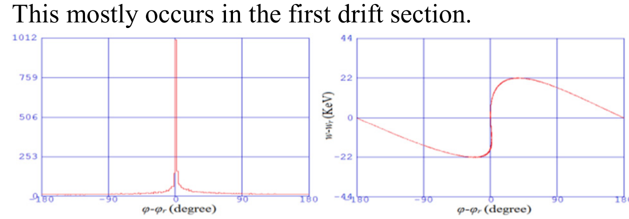
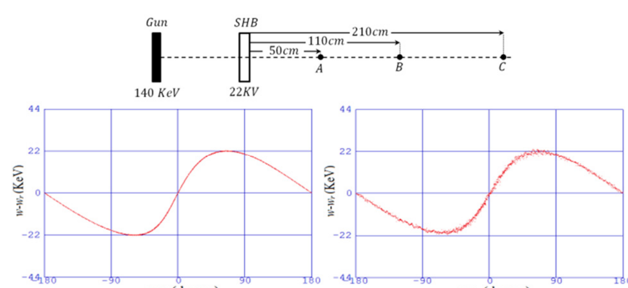
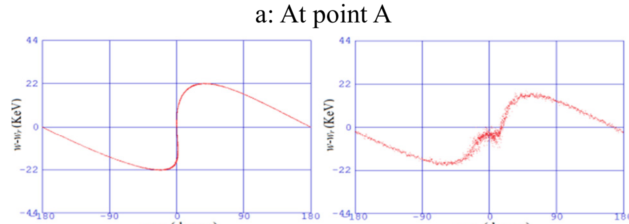


Figure 8: Phase spectrum (left) and phase space (right) of the beam at 110 cm away from a 22 KV SHB.

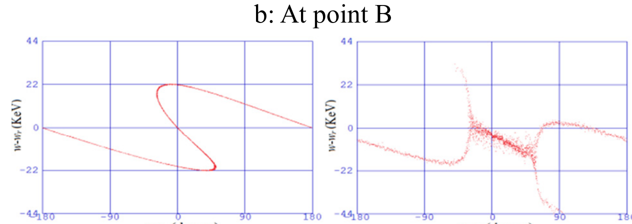
One can compare the phase space of the beam after passing through the first SHB ignoring the space charge effect and taking it into account in Fig. 9.



a: At point A



b: At point B



c: At point C

Figure 9: The phase space of the beam at several distances away from SHB ignoring the space charge (left diagram) and taking it into account (right diagram).

ISBN 978-3-95450-122-9

As shown in Fig. 9 the effect of space charge can hardly be seen at distances less than 110 cm where the phase spectrum becomes narrow. After this point the debunching effect of space charge forces starts. And at point C the phase space is completely different from the case of ignoring the space charge forces and the bunch length is much bigger. To reduce the disturbing effect of the space charge one should avoid long drift spaces, specially the first one. When the beam enters the second SHB the strong RF field of SHB reduces the effect of space charge forces. So in the optimization code we should restrict the maximum value of drift spaces. Following this procedure, Fig. 10 shows the phase space of the optimum configuration of the Fig. 7 with taking the space charge into account. After turning on the space charge, 91.6 percent of particles lie in the buncher acceptance and the satellite population becomes 5.4%.

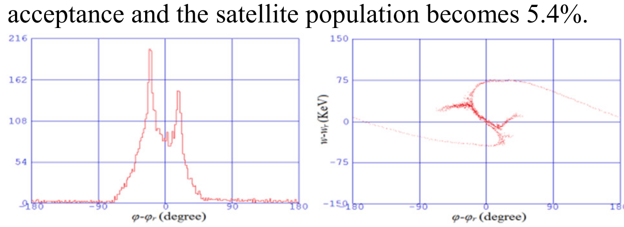


Figure 10: The phase spectrum (left diagram) and the phase space (right diagram) of the beam in thin lens model at the entrance of the buncher.

Travelling Wave SHBs

If we look to the phase space of the beam after passing through a 50 cm travelling wave structure SHB we will interestingly find out that it is very similar to the case of simple thin lens cavity.

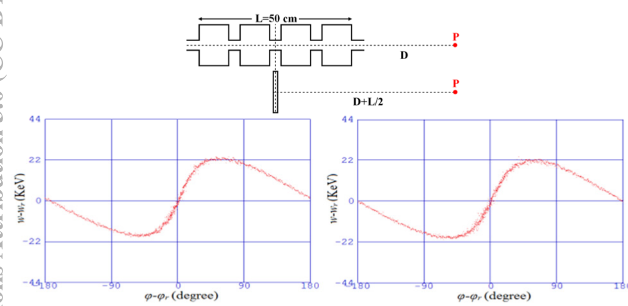
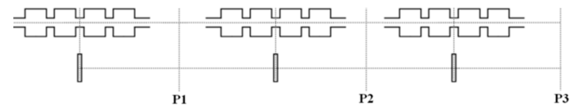


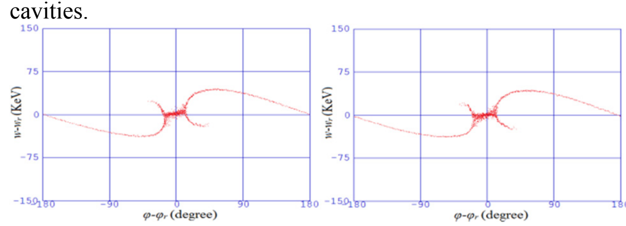
Figure 11: The phase space of the thin lens SHB (left diagram) and travelling wave SHB (right diagram).

This means that the thin lens approximation is a good approximation and the details of the electric field of the travelling wave structure is not important and the only important thing is the voltage of SHB (for the design of SHBs see [4]). To be sure, Fig. 12 provides more comparison been travelling wave structure and thin lens system.

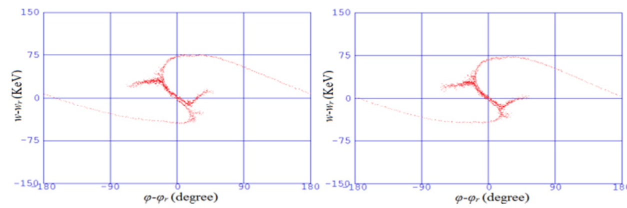
For the travelling SHB system 92.0 percent of particles lie in the buncher acceptance and the satellite population is 5.0%. The optimized parameters for 50cm travelling wave SHBs are given in Table 1.



a: Replacing traveling wave structure instead of thin lens cavities.



b: At point P2



c: At point P3

Figure 12: Comparison between thin lens system (left diagram) and travelling wave structure (right diagram) comparison at point P1 is given in Fig. 11.

Table 1: Optimized Parameters

SHB	Voltage(KV)	Phase(degree)	Drift(cm)
1	22	0	108.3
2	28	-5	9.0
3	34	-6	13.6

CONCLUSION

The optimization process of the sub-harmonic bunching system can be summarized as follows:

- We optimize the thin lens system with the computer code written in *MATHEMATICA*.
- Then we choose an optimum configuration in which the effect of space charge is low. This occurs in configurations with the shorter drift spaces.
- Finally we reconstruct the SHB system with the travelling wave SHBs instead of thin lens cavities according to Fig. 10-a.

REFERENCES

[1] A Multi-TeV linear collider based on CLIC technology: CLIC Conceptual Design Report, edited by M. Aicheler, P. Burrows, M. Draper, T. Garvey, P. Lebrun, K. Peach, N. Phinney, H. Schmickler, D. Schulte and N. Toge, CERN-2012-007.

[2] Stanford High-Energy Linear Electron accelerator (Mark III), p. 184, M. Chodorow et al, the review of scientific instruments, volume 26, number 2 (1955).

[3] Linear Accelerators, edited by Pierre M Lapostolle, Albert L. Septier, North-Holland Publishing Company, Amsterdam, 1970.

[4] H. Shaker et al., “Sub-harmonic Buncher Design for the CLIC Drive Beam Injector,” IPAC’13, Shanghai, May 2013, TUPME052.

ISBN 978-3-95450-122-9