AN INJECTOR FOR THE CLIC TEST FACILITY (CTF3)

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Abstract

The CLIC Test Facility (CTF3) is an intermediate step to demonstrate the technical feasibility of the key concepts of the new RF power source for CLIC. CTF3 will use electron beams with an energy range adjustable from 170 MeV (3.5 A) to 380 MeV (with low current). The injector is based on a thermionic gun followed by a classical bunching system embedded in a long solenoidal field. As an alternative, an RF photo-injector is also being studied. The beam dynamics studies on how to reach the stringent beam parameters at the exit of the injector are presented. Simulations performed with the EGUN code showed that a current of 7 A can be obtained with an emittance less than 10 mm.mrad at the gun exit. PARMELA results are presented and compared to the requested beam performance at the injector exit. Sub-Harmonic Bunchers (SHB) are foreseen, to switch the phase of the bunch trains by 180 degrees from even to odd RF buckets. Specific issues of the thermionic gun and of the SHB with fast phase switch are discussed.

1 INTRODUCTION

The CTF3 construction [1] will start in 2001. It is foreseen in 3 stages and the injector will also have 3 stages [2] of development. The first one is called "Preliminary stage". The injector is the same as the present one used for LIL [3] except for the thermionic gun. The second one is called "Initial stage". The injector has all new components (gun, bunching, focusing, and matching systems) and should deliver the nominal current with all RF buckets filled. The third one is called "Nominal stage". The preliminary stage is identical to the previous one except that SHBs will be added. Even and odd trains are generated with every other bucket filled. The concepts of fully-loaded linac and SHB with fast phase switch are explained in [1]. However the process produces unwanted satellite bunches. Table 1 summarises the beam parameters requested at the injector exit for the 3 stages.

| Parameters                  | Unit  | Pre. | Init. | Nom. |
|-----------------------------|-------|------|-------|------|
| Beam energy                 | MeV   | 4    | 5     | 1.5  |
| Beam pulse                  | µs    | 2.53 | 1.54  | 1.54 |
| RF pulse                    | µs    | ≥3.8 | ≥1.6  | ≥1.6 |
| Beam current                | A     | 0.3  | 3.5   | 3.5  |
| Gun current                 | A     | 1    | 7     | 7    |
| Charge/bunch                | nC    | 0.1  | 1.17  | 2.33 |
| Bunch spacing               | m     | 0.1  | 0.1   | 0.2  |
| Bunches/pulse               |       | 100  | 4200  | 2100 |
| Charge/pulse                | nC    | 10   | 4893  | 4893 |
| Charge/satellite            | %     | -    | -     | -    |
| Bunch length                | ps- fwhh | 7 | ≤12   | ≤12  |
| Bunch length                | mm-rms| 0.9  | ≤1.5  | ≤1.5 |
| Normalised rms emittances   | mm.mrd| 50   | ≤100  | ≤100 |
| Energy spread (Single bunch)| MeV  | ≤0.5 | ≤0.5  | ≤0.5 |
| Energy spread (on flat-top) | MeV  | -    | ≤1    | ≤1   |
| Charge variation bunch-to-bunch | %  | ≤20  | ≤2    | ≤2   |
| Charge flatness (on flat-top)| %  | -    | ≤0.1  | ≤0.1 |
| Beam rep. rate              | Hz    | 50   | 5     | 5    |
| RF rep. rate                | Hz    | 100  | 30    | 30   |
2.2 Layout

Figure 1 shows the layout for the Nominal stage. After the thermionic gun (140 kV), there are 3 sub-harmonic bunchers SHB (1.5 GHz), one pre-buncher PB1 (3 GHz), one buncher B1 (3 GHz, 6-cells TW) and 2 accelerating structures S1/S2 (3 GHz, 32-cells TW). All components between the gun and the injector exit are embedded in a solenoidal field (SNL). A matching section with beam collimation and beam diagnostics is located between the injector and the Drive Beam accelerator.

3 EGUN SIMULATIONS

For the Preliminary stage, the new thermionic gun provides 2 A at 90 kV. A classical Pierce gridded gun, called CLIO [5], is proposed. It has a thermoelectronic dispenser cathode with an emitting surface of 0.5 cm$^2$, grid-cathode spacing of 0.15 mm, cathode-anode distance of 24 mm and anode hole diameter of 8 mm. The electrode geometry was modelled using the EGUN code [6]. The beam radius does not exceed 10 mm between the anode and 125 mm downstream of the anode, where a capacitive electrode allows beam current measurements. The normalised emittance is 7 mm.mrad, 62 mm downstream of the cathode. For the Initial and Nominal stages, the thermionic gun should provide 7A at 140 kV, with 150 kV voltage capability. A thermionic gun of the SLAC-type is proposed. It has a dispenser cathode with an emitting surface of 2 cm$^2$, cathode-anode distance of 45 mm and an electrode angle 45°. Figure 2 shows the field lines and electron trajectories. Simulations in a space-charge-limited regime with thermal effect (1223 K) give a normalised emittance of 9.5 mm.mrad at $z = 120$ mm for a beam current of 7.4 A (perveance 0.128 $G_50$). However, PARMELA simulations start at the anode exit. At this place, the normalised emittance is 7 mm.mrad. The maximum electric field on the contour is less than 10 MV/m.

4 PARMELA SIMULATIONS

4.1 Longitudinal beam dynamics

Extensive simulations [7,8] are performed with PARMELA code at CERN, LAL and SLAC. They start from the gun exit with an initial normalised emittance of 7 mm.mrad, and 140 keV kinetic energy of the reference particle. The total number of particles is 6000 over a range of 6 S-band cycles. One of the issues is to make the satellite charge (in a 20° window) less than 5% of the main bunch (in a 20° window). Results are based on beam dynamics simulations assuming 400 kW RF power for 3 SHBs. Figure 3 shows the phase spaces obtained at the injector exit. The bunch length at the end of the injector is close to 10 ps (fwhm) and about 82% of the particles are captured in 20°. Studies are going on based on a cluster of 3 sub-harmonic bunchers with 3 different frequencies: 1.5 GHz, 3 GHz, 4.5 GHz. Preliminary results, not discussed here, with a bunch length of 10 ps and a normalised rms emittance of 40 mm.mrad give 3% charge in the satellites.
To simulate the transverse beam dynamics correctly, different mesh sizes are chosen for different regions. Emittance variations are studied as a function of the strength and shape of the solenoidal magnetic field. An optimum is found for a value of 0.1 T along the 2 accelerating structures, with a maximum value of 0.2 T in the buncher. Table 2 compares the simulation results with the goal.

Table 2: Comparison between simulations and requirements

| Parameters                  | Simul. | Goal |
|-----------------------------|--------|------|
| Energy (MeV)                | 20     | ≥ 20 |
| Satellite charge (%)        | 5      | ≤ 5  |
| Bunch length (fwhm, ps)     | 10     | ≤ 12 |
| Bunch length (fwhm, ps)     | 20     | ---  |
| Energy spread (fwhm, MeV)   | 0.25   | 0.5  |
| Charge/bunch (nC)           | 2.51   | 2.33 |
| RF power for 3 SHBs (kW)    | 400    | Minim. |
| Normalised rms emittance    | 33     | ≤ 100 |

5 GUN AND SUB-HARMONIC ISSUES

For the Preliminary stage the CLIO gun will replace the present one in the LIL tunnel. For the following stages (150 kV, 7 A) voltage and current stability of ≤ 0.1% are requested on the flat-top. To obtain such performances, high voltage capacitors will be installed on a modified SLAC-type gun. Under these conditions the stored energy will be 1 kJ and a gun protection system has to be designed.

Concerning the SHBs 1.5 GHz, the PARMELA optimisation gives a gradient of 0.4 MV/m over a gap of 4 cm. This will require a voltage of 16 kV. Based on HFSS simulation [9], a power of 124 kW is needed at the input of each SHB. For 3 SHBs a total power of 372 kW will be necessary. A fast phase switch of the order of 3 to 4 ns is envisaged for the SHBs. It could be difficult to build a SHB with very low Q (~10) and to provide a 400 kW power supply at 1.5 GHz with large bandwidth.

6 CONCLUSION

The Preliminary stage of the CTF3 injector is being implemented. For the Nominal stage, a configuration of the injector has been found which fulfills the requirements of CTF3. The Initial stage should be easy to implement since it is a simple version of the Nominal stage. However, several steps will still be needed in order to improve the beam performance at the injector exit before starting the design of the RF cavities.

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