DESIGN OF A HIGH CURRENT ELECTRON SOURCE FOR THE CLIC DRIVE BEAM INJECTOR

S. Doebert, N. Chritin, CERN, Geneva, Switzerland
J. Gardelle, B. Cassany, B. Cadilhon, K. Pepitone, CEA/CESTA, Bordeaux, France

Abstract

The drive beam injector for CLIC needs to deliver a 4.2 A electron beam for a duration of 140 μs with a repetition rate of 50 Hz. The shot to shot and flat top current stability has to be better than 0.1% to guarantee the beam stability required for CLIC. Based on the experience with the CTF3 injector, a thermionic high voltage gun with a gridded cathode has been designed together with a sub-harmonic bunching system to achieve these requirements. The grid will allow controlling the current and eventually feed back on the flat top shape. The gun will operate at 140 kV and an emittance of 14 mm mrad can be obtained. The paper describes the design approach and the results of the systematic electromagnetic simulations to optimize the gun. Care was taken during the mechanical design of the gun to obtain a modular design allowing adjusting for different beam currents and cathode sizes.

INTRODUCTION

In the two beam acceleration scheme of the Compact Linear Collider (CLIC) the drive beam serves as the power source for the main linac [1]. This drive beam is a low energy, high current beam where the beam power is extracted locally by deceleration and directly fed into the main linac. Therefore the beam stability of the main beam is critical to obtain the desired luminosity determined by the stability of the drive beam. This dependence put severe stability requirements on the drive beam injector. In CLIC the drive beam is generated from a 140 μs long DC electron beam, bunched at a sub-harmonic frequency of 500 MHz and then accelerated with an rf frequency of 1 GHz. The sub-harmonic bunching is used to phase code the beam to enable beam combination using rf deflectors and a series of combiner rings. In the end the long bunch train gets combined to 24 sub-trains which are each 240 ns long and have a 12 GHz bunch repetition rate. The average beam current gets increased from 4.2 A to 100 A during this process (see [1] for more details).

The drive beam injector consists of a thermionic gun, three sub-harmonic buncher cavities, a pre-buncher, a travelling wave buncher and fully loaded accelerating structures [2, 3]. A sketch of the drive beam front end is shown in Fig. 1. This paper concentrates on the electron source itself, which has to deliver a beam with the following parameters. The current needed from the gun to obtain 4.2 A average current or a bunch charge of 8.4 nC after bunching is about 5 A according to the injector simulations. Nevertheless a certain flexibility to increase the current should be taken into account for the gun design. The high average current and long pulse length is a major challenge for the cathode-grid assembly while the

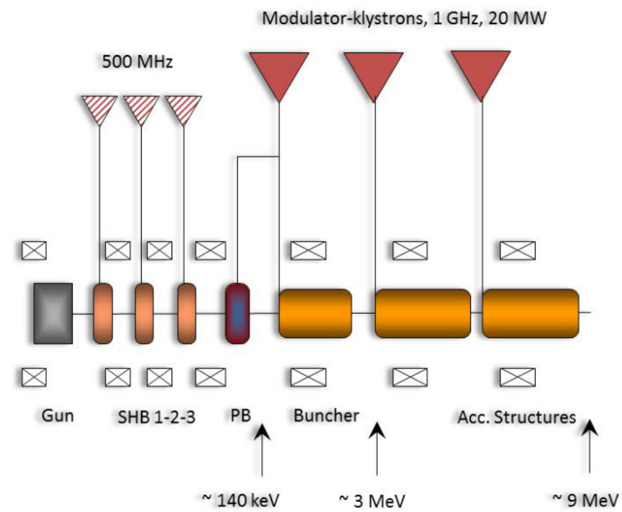

Figure 1: Layout of the CLIC drive beam injector front end. From left to right: Thermionic gun, 500 MHz sub-harmonic bunchers, 1 GHz pre-buncher, 1 GHz travelling wave buncher and two 1 GHz accelerating structures.

required current stability puts severe constraints on the high voltage power supply. The high voltage will be supplied by a solid state modulator currently under development in collaboration with CEA/CESTA.

Table1: Main electron source parameters

Gun voltage	140 kV
Beam current	5 to 7 A
Pulse length	140 μs
Repetition rate	50 Hz
Emittance (rms)	< 20 mm mrad
Shot to shot charge variation	0.1%
Flat top charge variation	0.1% after correction
Average beam power	4.9 kW

ELECTRON GUN DESIGN

The electromagnetic design of the CLIC drive beam gun was done in collaboration between CEA/CESTA and CERN. The emphasis of the study was to obtain a focusing electrode geometry which allows operating the gun in a wide range of currents without compromising too much on the emittance of the generated beam. The design is based on the assumption that a commercial cathode grid assembly can be used. The grid is essential because it allows regulating the current of the gun and eventually could be used to correct the shape of the generated current pulse independent of the high voltage. We studied two different cathode assemblies produced by CPI/Eimac [4]

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for the design YU156 and Y 796. The difference between the two assemblies is the size and current capabilities of the planar cathodes. The investigated geometries are based on the CTF3 gun developed by SLAC within the CLIC collaboration [5, 6]. The geometry consists of a planar cathode with a radius of 8 or 10 mm and a focusing electrode starting with a 22.5 deg angle. The angle is increased to 45 deg further away from the cathode. The corresponding anode uses a 45 deg angle as well (see Fig. 5).

Numerous simulations have been done using the ray tracing code EGUN [7] and the 2D PIC-code MAGIC.[8] Variations of the above described geometry, in particular changing the angles of the focusing electrodes and the cathode-anode distance have been simulated. In addition the voltage of the gun has been studied in the range of 100 to 200 kV to understand the influence on the design. The geometry was optimized for a nominal current of 5 to 7 A. Fig. 2 shows an example of the current dependence of the emittance for the CTF3 geometry and a cathode optimized for currents between 7 and 9 A. It was found that the actual geometry of the focusing electrode and anode is less critical to obtain a beam with a satisfying emittance. The main parameter to adapt for different currents and gun voltages was found to be the cathode-anode distance. Therefore it was decided to aim for a mechanical design which allows adjusting this parameter.

The obtained results from EGUN and MAGIC have been compared as shown in Fig. 3. We found a fairly good agreement between the two codes with the exception of the particles in the outer radius regions of the beam, indicating that certain edge effects are treated differently in the two approaches. No further study has been done so far to investigate this discrepancy.

The baseline for the new CLIC drive beam source is using the larger YU156 cathode with 3 cm^2 emission surface. In an optimized electrode configuration a geometrical rms-emittance of 14.5 mm mrad for a 5 A beam can be expected. This kind of beam quality can be preserved as well for a 7 A beam current and fully satisfies the requirements. These simulations do not take into account the grid which is expected to increase the emittance slightly. The gun voltage was chosen to be 140 kV as it is the case for CTF3 mainly due to constraints of the subsequent bunching system [2]. The maximum voltage on the surface of the electrodes was found to be 140 kV/cm.

In addition to the ray tracing and PIC simulation an analytical method was used to calculate the optimal electrode shape for a minimal emittance. The approach assumes uniform beam distributions with changing radius and resulted in an ideal parabola shape which can be well approximated with the two different angles used in the design described above [9]. First simulations with this geometry indicate a possible emittance reduction compared to the above described electrodes.

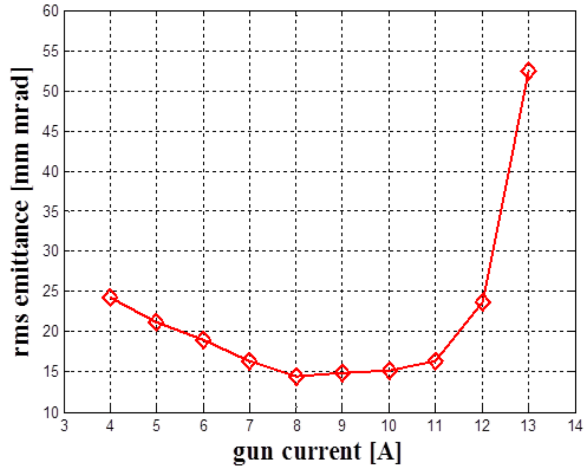

Figure 2: Current dependence of the emittance for the 8 mm cathode in the CTF3 gun.

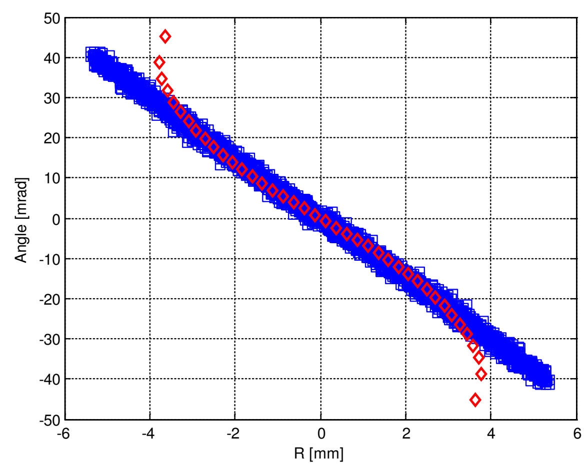

Figure 3: Comparison of the phase space at the exit of the gun as simulated by EGUN (red) and MAGIC (blue). This simulations are for a 5 A beam from a 10 mm radius planar cathode, evaluated at the exit of the anode.

MECHANICAL DESIGN

The mechanical design aimed at providing a modular approach for the different gun parts enabling the use of different types of cathodes and exchangeable focusing electrodes. This would allow adapting easily the mechanical design for a wider range of beam parameters. Traditionally thermionic guns using high voltage used a sealed design applying welding and brazing techniques to achieve a low pressure and clean surfaces. The drawback is of course that the assembly has to be cut open to change electrodes or in case of a high voltage insulator failure. The CLIC gun uses a commercial insulator [10] with Conflat flanges and a demountable anode in a separate vacuum tank. This allows exchanging the anode and adjusting the cathode-anode distance to adapt for different beam currents or voltages. Finally any cathode assembly which is mounted on a CF 40 flange can in principle be used in the gun.

Fig. 4 shows the 3D model of the entire set up designed to test the gun with nominal beam conditions currently under construction at CERN. The beam line consists of the gun itself, which is separated by a vacuum valve followed by a current transformer, a pumping port and a beam dump. The beam dump is made out of a graphite cone, which can survive the full length electron beam. The electron beam is stopped in a surface layer of about 15 µm at these low energies. The dump is water cooled to handle the high average beam power. Later on it is planned to add a profile monitor to measure the beam emittance but likely this monitor will be only able to operate at a short pulse length of a few µs. Two solenoid coils (not shown in Fig. 4) will be used to focus the beam. This setup will be used to study the stability of the produced electron beam.

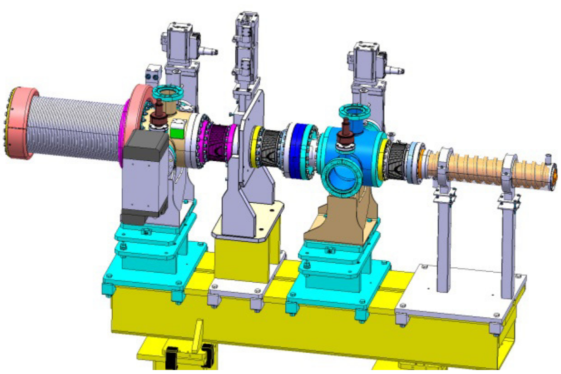

Figure 4: Mechanical layout of the gun test beam line including the high voltage ceramic (left), pumping ports, a current transformer and a beam dump.

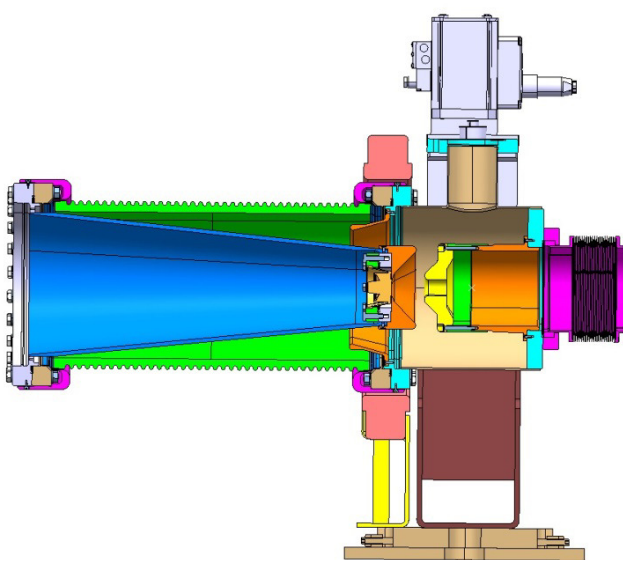

Figure 5: Mechanical design of the thermionic electron source consisting of a conical structure (blue) holding the cathode (orange) inserted into the insulation ceramics (green) and a separate anode (yellow) chamber.

The mechanical design of the gun itself can be seen in more detail in Fig. 5. The gun is based and supported by a directly pumped vacuum chamber which holds the anode of the gun assembly. The anode can be adjusted for alignment with respect to the cathode, and the distance between the two electrodes can be adapted by changing a spacer ring. The commercial high voltage insulation ceramic was fitted with standard Conflat flanges and is bolted directly onto the anode vacuum chamber. The centrepiece of the gun is then the conical structure which holds the cathode assembly. This structure is supported by a Conflat flange which connects to the ceramic. The cathode again on a Conflat flange is assembled into the centre of the conical structure. Corona rings outside and inside the vacuum protect the triple points in the high field areas. High quality stainless steel will be used to realize the gun assembly. The modular design allows to test different cathodes and to adapt easily the relevant geometry to obtain an optimized emittance for different beam current and voltages if needed.

CONCLUSION

A modular thermionic gun has been designed for the high average charge injector for the CLIC Drive Beam. The challenges are in the high average current and severe stability requirements. The electrode configuration has been optimized using ray tracing and PIC simulations for a range of beam currents. The normalized emittance for a 5 A beam can be expected to be around 11.3 mm mrad. This emittance and the obtained phase space distribution have been used as input to the simulation of the entire injector and are satisfying the requirements for CLIC drive beam. The modular mechanical design should be useable for a number of projects in need of a high current electron source because of its adaptability to a range of beam parameters. One potential user might be the ADELE project of CEA/CESTA.

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