LEETCHI: THE HIGH CURRENT ELECTRON SOURCE FOR THE CLIC DRIVE BEAM INJECTOR

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Abstract

LEETCHI is a source which will produce 140 keV, 5 A, 140 µs electron beams at a repetition rate of 50 Hz. The shot to shot and flat top current stability of this drive beam injector for CLIC has to be better than 0.1 % and a geometrical rms-emittance of 14 mm.mrad is expected. The development of a high voltage modulator, to achieve those requirements, is ongoing. A small test stand has been built which allows to diagnose and dump the beam produced by the thermionic cathode. The thermionic cathode is equipped with a grid which will allow us to control the current and eventually to have a feedback on the flattop shape. The beam dump, made of graphite, has been designed using two different codes, the Monte Carlo code GEANT4 to simulate the energy deposition and ANSYS used to simulate the thermal resistance of the graphite due to the long pulse duration. The geometry has been optimized with the ray tracing code EGUN and the 2D PIC-code MAGIC. All these simulations allowed us to optimize the geometry of the gun and to develop diagnostics which must survive to the heat deposition. Finally, the first electrical measurements of the beam will be presented.

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. The beam stability of the main beam is critical to obtain the desired luminosity and thereby determined by the stability of the drive beam. This dependence puts 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 [2–4]. A sketch of the electron source is shown in Figure 1. The DC 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 injector simulations [1]. The high average current and long pulse length is a major challenge for the cathode-grid assembly while the required current stability puts severe constraints on the high voltage power supply. Electron source parameters are given in Table 1. The high voltage will be supplied by a solid state modulator currently under development.

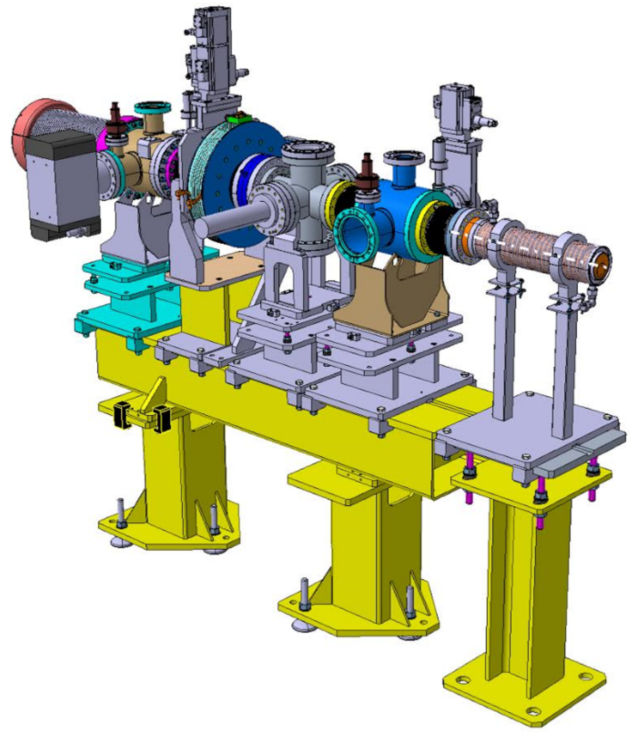

Figure 1: Mechanical layout of LEETCHI including the high voltage ceramic (left), a current transformer, an optical diagnostic and a beam dump.

Table 1: Electron Source Parameters

Parameters	Values
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 power	4.9 kW

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ELECTRON GUN DESIGN

The electromagnetic design of LEETCHI 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. The geometry is 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 10 mm and a focusing electrode starting with a 22.5 ° angle which is increased to 45 ° angle further away from the cathode. The corresponding anode uses a 45 ° angle as well (see Figure 2).

Numerous simulations have been done using the 2D PIC-code MAGIC [7] and the ray tracing code EGUN [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 [4]. The geometry was optimized for a nominal current of 5 to 7 A extracted from the YU156 cathode produced by CPI/Eimac. In an optimized electrode configuration a geometrical rms-emittance of 14 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 (at the surface of the cathode) 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 14 kV/cm. According to energy deposition and thermal simulations, respectively performed with the code GEANT4 [9] and ANSYS®, a dump was designed to safely absorb the beam. Because of the low energy of electrons, the energy deposition is very high at the surface of the dump. In addition, the high pulse length, the repetition rate and the high current beam complicated the design of the dump [10].

BIAS AND PULSER CIRCUITS

To connect 3 power supplies (Heater, Bias and Pulser) to the cathode, a connector has been developed. The electrical circuit of the Bias and Pulser power supplies is given in Figure 3. On this schematic, the grid of the cathode is the reference voltage. The Bias applies a positive DC voltage, blocking the electrons from the cathode, while the Pulser superposes a negative voltage to extract the pulsed electron beam. The amplitude and duration of the negative voltage defines the beam current and the duration.

The pulser has to deliver the total current of 5-7 A. The pulser is based on the discharge of C1, a large capacitor in order to maintain a long flat pulse on the cathode. R13 is used for self-discharge of C1 after operation. C1 is charged by an external positive power supply controlled by a delay generator. The negative pulse is applied to the cathode when the IGBT is switched. With 50 Ω termination, the R3/R9 voltage divider gives a 1:100 ratio. R2 resistor limits the current in case of Cathode-Grid short circuit. C5 helps to improve the rise time of the current. During the pulse, the bias power supply is insulated by the L2/L3 inductors.

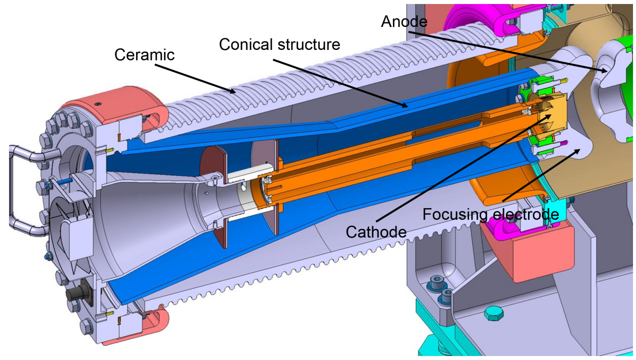

Figure 2: Mechanical design of the thermionic electron source consisting of a conical structure holding the cathode inserted into the insulation ceramics and a separate anode chamber.

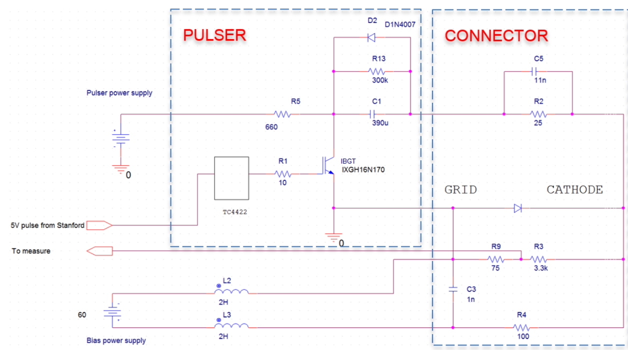

Figure 3: Schematic of the Bias and Pulser power supplies.

CONDITIONING

The conditioning of the gun has been done in several steps. After assembly and once it was under vacuum, the high voltage was gradually increased to the nominal value. During the high voltage conditioning, only few breakdowns were observed, thus we conclude that the geometry has been properly defined. Figure 4 gives the variations of vacuum as a function of time for voltages between 136 kV and 143 kV.

Once this first step was finalized, the high voltage was turned off and the Heater was turned on to activate the cathode respecting the parameters provided by CPI-Eimac. The heating resistor is less than 1 Ω and its value varies as a function of the temperature. The operating temperature is of the order of 1000 °C. Figure 5 presents the current and voltage from the heater power supply and the variations of the vacuum during the conditioning.

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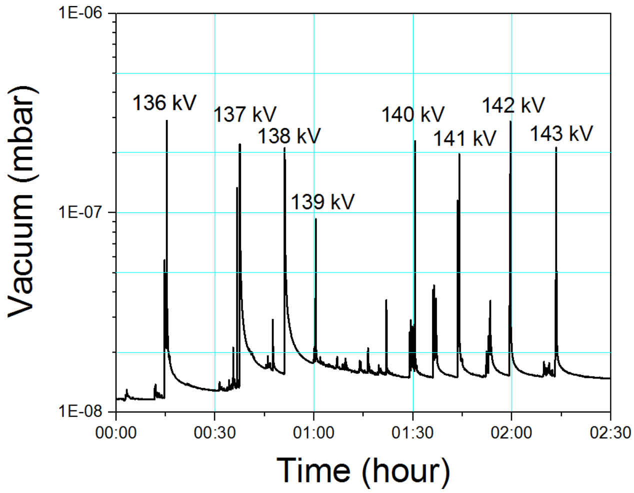

Figure 4: Variations of the vacuum during the high voltage conditioning.

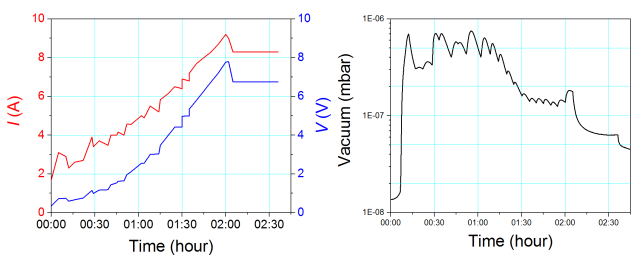

Figure 5: Current and voltage applied to the cathode (left) and variations of the vacuum (right) during the cathode conditioning.

In the final step, the Bias, the Heater and the high voltage power supplies were turned on and set at the nominal values. No major fault were detected, LEETCHI is ready for the first electron beam by switching on the Pulser power supply.

EXPERIMENTAL RESULTS

The dump is not yet installed on the electron source. Consequently, it is not possible to generate a 5 A beam with a duration of 140 µs. However, stability measurements were performed with an electron beam of 120 kV, a current of 0.8 A and a pulse width of 3 µs. In these tests, 500 shots were produced at a frequency of 0.2 Hz. The curves of the measured currents and the cathode grid voltages are given in Figure 6, it shows that the stability is of the order of 0.19% (1 σ). These preliminary results are encouraging and in agreement with the requirements of the gun.

CONCLUSION

The CLIC drive beam electron source LEETCHI was put into operation successfully with short electron pulses.

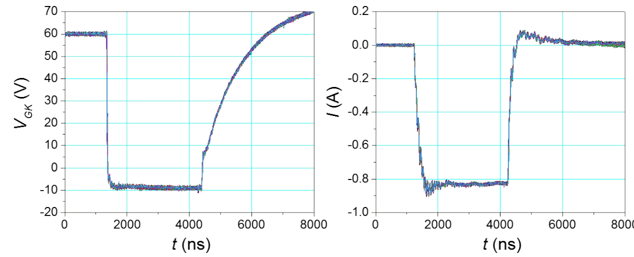

Figure 6: 500 shots at 0.2 Hz with an electron beam of 120 kV, 0.8 A and a pulse length of 3 µs.

The first results are satisfying, the next step is to install the beam dump to increase the pulse length and the current. A silicon carbide target will be also installed to characterize the beam using OTR. According to the simulations performed with different codes, the emittance, for a 5 A beam, can be expected to be around 14 mm.mrad. Due to the low energy electron, the angle between the target and the beam will be equal to 25 °. 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.

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