ELECTRON GUN FOR THE FEL CLIO

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Summary

A triode electron gun has been developped and manufactured at LURE (Laboratoire pour l'Utilisation du Rayonnement Electromagnétique) and LAL (Laboratoire de l'Accélérateur Linéaire) for the free electron laser CLIO[1] (Collaboration pour un laser à électrons libres dans l'infrarouge à Orsay) now under construction : this gun involves a grid-cathode assembly manufactured by EIMAC, currently used in the SLAC gun family.

For the FEL requirements, the gun must be able to yield a train of shorts pulses at accuracy frequency or a continuous pulse.

Driving together the cathode and the grid the gun produces a continious beam of 12 µs or a pulsed beam of very short pulse of 1 ns at 250 MHz, 125 MHz, 62.5 MHz or 31.25 MHz. The performances of the gun has been tested on a testing bench. A peak current of 1 Amp. for 1 ns width at any frequencies was achieved at an injection voltage of 90 kV.

Introduction.

The free electron laser CLIO is designed to be broadly tunable in the infrared range from 2 to 20 µm with an average power of 10 to 100 W.

It is driven by a S band Linac of 50 to 80 MeV that yields some micropulses of 1 nC (100 Amp., 10 ps) at the frequency required for the laser (even multiple of 31.25 MHz up to 500 MHz). By the subharmonic bunching process the gun must produce only 1 Amp., 1 ns pulses every 4, 8, 16 or 32 ns during all the 12 µs macropulse in synchronism with the R.F. frequency at 500 MHz of the subharmonic cavity.

A peak gun current of 1 Amp. to 1.5 Amp. was aimed with a width shorter than a half period of the RF frequency i.e FWHM
< 1ns in order to avoid too larges parasitics bunches.

Electron gun

This gun is called "SLL gun" from SLAC for the original design[2], LAL and LURE for the development and manufacture. This gun is a classical Pierce gridded gun with a thermoelectronic dispenser cathode. Mechanically the gun frame is designed to fit several cathodes manufactured by EIMAC. The Y 646 B, Y 845 or Y 796. This later model will be used in a further version of our FEL. The gun structure is shown in Fig. 1. At this time we use the Y 646 B model, the cathode has a 8 mm diameter and the grid-cathode spacing is 0.15 mm with a screening fraction of about 15% to 20%.

Keeping the filament voltage and current at their nominales values 6.3 V and 1.4 Amp., the peak cathode current can reach up to 2.5 Amp. for a grid-cathode net drive of 70 V.

Like we need only 1 Amp. to 1.5 Amp. this cathode is sufficient. The gun electrode geometry was modeled using the "ETP Hermannsfeldt code" of SLAC[3] in order to get the smallest emittance for 90 kV and 1.5 Amp. The code predict an emittance $\varepsilon^N = 2\ \pi$ mm mrad very close to the cathode emittance alone. However for smallest currents the emittance grows.

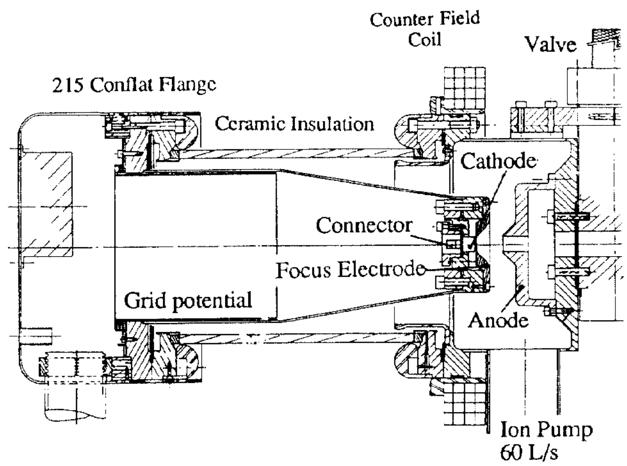

Fig. 1 Structure of the gun assembly

We have roughly evaluated the grid lens effect and finally estimated a normalized emittance $\varepsilon^N \approx 15\ \pi$ mm mrad in the range of 0.5 Amp. to 1.5 Amp. at 90 kV.

The distance between the cathode and anode is 24 mm and the anode hole diameter is 8 mm. At the cross over the beam diameter is 2.6 mm. Fig. 2 shows the calculated beam trajectories.

The ceramic isolator is designed to withstand up to 200 kVDC. Each side is brazed on a 215 conflat flange surrounded by anticorona rings. This ceramic isolator was especially manufactured by SCT CERAVER France.

The vacuum chamber is large enough to receive another set of more large electrodes used with the 4796 cathode.

COMPUTED BEAM TRAJECTORIES FOR $I/V^{3/2}$ = .055 µPV

Cathode Y 646 B 0.5 cm²

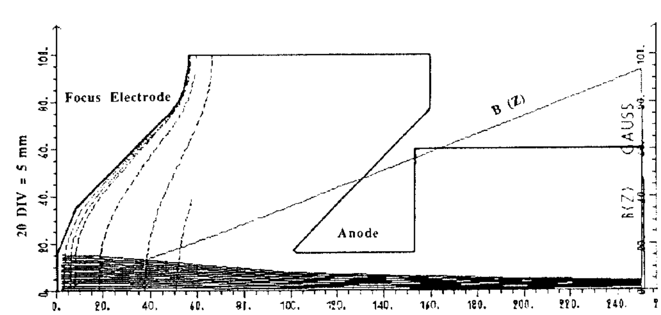

Fig. 2 Computed beam trajectories from the cathode to the cross over

The cathode anode space is pumped down through a good conductance pipe of diameter 65 mm by a 60 l/s ion pump. The pressure while the gun is running is between 10^{-8} and 10^{-9} Torr. This pressure is sufficiently low for a dispenser cathode. Directly on the gun chamber a gauge monitor the pressure.

All the pieces under vacuum that must withstand a high electric field have been polished and baked before assembly. And a last baking of the whole gun was performed at 180°C to reduce the water vapor more than 36 hours. The process of cathode activation was started when the pressure fell under 10^{-6} Torr. The high voltage conditioning was performed up to 100 kVDC for a nominal rating value of 90 kV, with a serial resistor of several meghoms in order to avoid too severe sparks between electrodes.

A counter-field coil located in the cathode plane cancel the residual magnetic field from the air coil on the Linac. Inside the gun the magnetic field increases from zero at the cathode with a gradient of 1 k Gauss/meter.

Pulser system.

The triode gun is driven by the cathode and the grid. In the "CW mode" the grid alone drives the triode with a large positive pulse of 12 µs 100 V. The pulse width is controled from the ground level by optical link.

In the pulsed mode, a 500 MHz 2 W signal during 16 µs is carried to the high voltage deck throught an isolated HF transformer made of two coupled loops of H.V. isolated cable, with an insertion loss of -3dB. A frequency divider (very fast ECL technology from PLESSEY) controled from the ground level throught optical links, elaborates the pulsed signal of 0.9 ns width every 4, 8, 16 or 32 ns which will be amplified in negatives pulses up to -110 V/1.2 ns by a wideband solid state amplifier 10 - 500 MHz, and applied on the cathode. This power amplifier has been especially developed for yield negative pulses as short as possible, by NUCLETUDES S.A. a french manufacturer.

In the same time the grid pulse of adjustable duration is used for doing a window that eliminate the first microsecondes while the power amplifier has small amplitude oscillations.

With a minimum grid bias of -20 V, beam micropulses of 1.5 Amp./1.4 ns were achievied.

Along the 12 µs, the residual macropulse amplitude droop is compensated by an adjustable counter voltage slope applied on the grid up to ± 10 mA/µs.

The average cathode and grid currents are monitored by two currents transformer on their connexions, and measured from the ground level by the way of analogical opto-link.

In the "CW mode" the total charge aimed in the macropulse is 6 µC (0.5 Amp. 12 µs) a 15 nF buffer capacitor in the H.V. supply yields this charge and keep constant the high voltage at 4 x 10^{-3}. Fig. 3 shows a block diagram of the modulator.

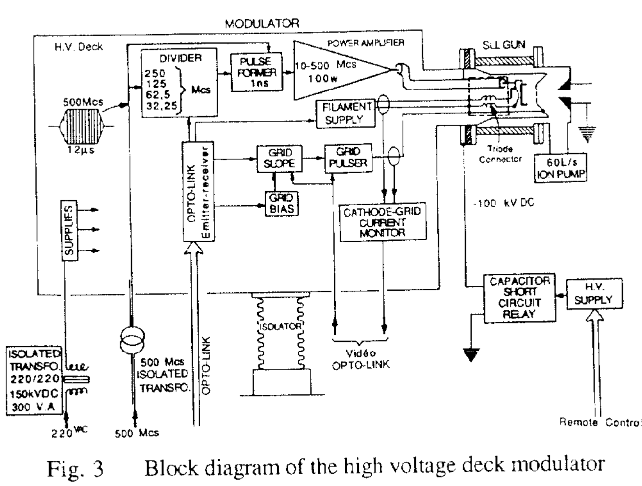

Fig. 3 Block diagram of the high voltage deck modulator

Control

The gun modulator is remote controlled by a 68008 MOTOROLA microcomputer in G 64 standard crates. From the control room, a program automatically starts the gun and put the parameters at their rating values.These program are wrote in C language.

Characteristics of the electron gun.

The cathode and grid currents are measured on long pulse 12 µs from the H.V. deck modulator by an analogical opto-link.

On the testing bench the beam current has been measured by a coaxial target and a cylindrical pick up electrode. The target has a characteristic transfert impedance of 10 Ω and allow to measured both short or long pulses, but the current absolute value may be disturbed by a secondary emission. For a more accurate measure we use the cylindrical pick up electrode which no intercepte the beam, its sensitivity is 0.5 V/Amp. for a beam of 90 keV.

A 7104 Tektronix oscilloscope 1 GHz bandwidth was used because the low repetition rate of 1 to 50 Hz.

The figure 4 shows the cathode emission characteristics as a fonction of filament voltage in the range of 1.5 Amp. of cathode current with a grid net drive of 30 V. At 6.3 V filament voltage, the gun works in space charge region and at this cathode temperature the dark current emitted by the grid is lower than 0.1 µAmp., but it rapidly increases for filament voltage upper to 7 V.

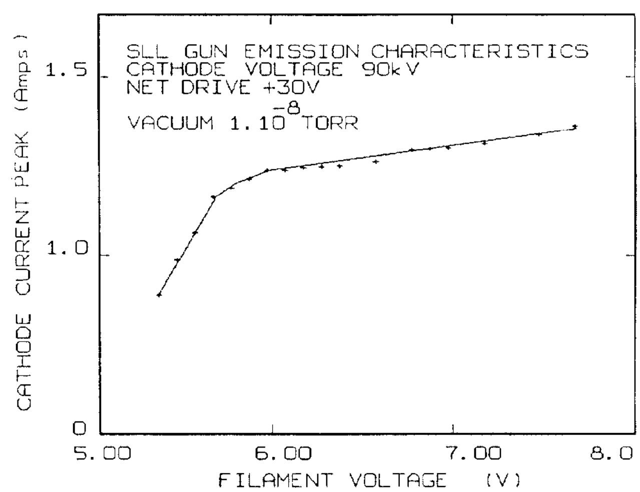

Fig. 4 Emission characteristics of the dispenser cathode Y 646 B

In the space charge rate, the cathode current follows the general equation of triode $I_K = G(Vg + Vp/\mu)^{3/2}$ with an amplification factor $\mu \approx 10^4$ and a perveance $G \approx 5.2 \times 10^{-3}$ A/$V^{3/2}$. The cut off amplification factor is µ C.O. ≈ 6600.

The grid interception or screening fraction depends of the grid and anode/cathode voltages for 90 kV anode potential, it increases about lineary with the cathode current from 12% at 0.5 Amp. up to 21% at 2.6 Amp.

The Fig. 5 shows the transfer characteristics in short pulses at filament voltage 6.3 V the maximum anode current available is limited by a perveance of 0.15 µAmp./$V^{3/2}$.

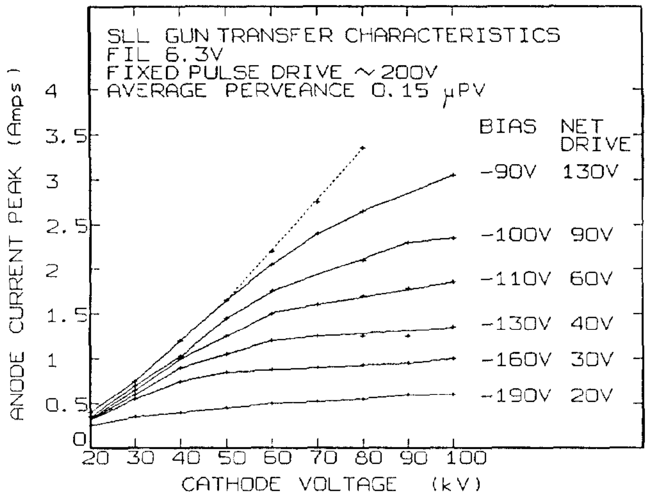

Fig. 5 Gun transfer characteristics in short pulse of about 1 ns

Fig. 6 shows the wave form of a short pulse beam during the 12 μs macropulse. It has been measured by the pick up electrode and the 7104 oscilloscope with a time resolution measured of 370 ps. For 1 Amp. peak the rise time is 470 ps and 1.1ns (FWHM).

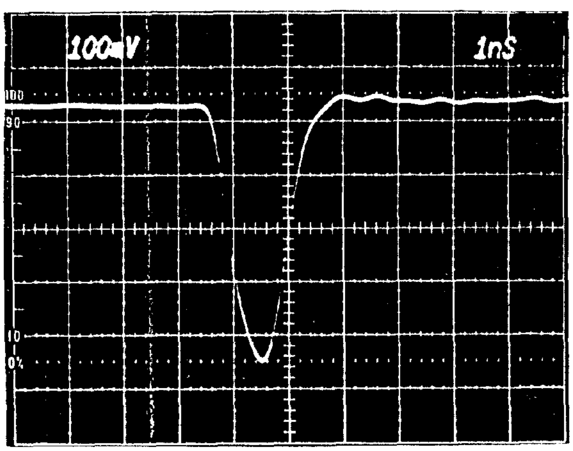

Fig. 6 Pick up electrode signal, waveform of a short pulse of 1 Amp. peak 470 ps rise time and 1.1 ns (FWHM)

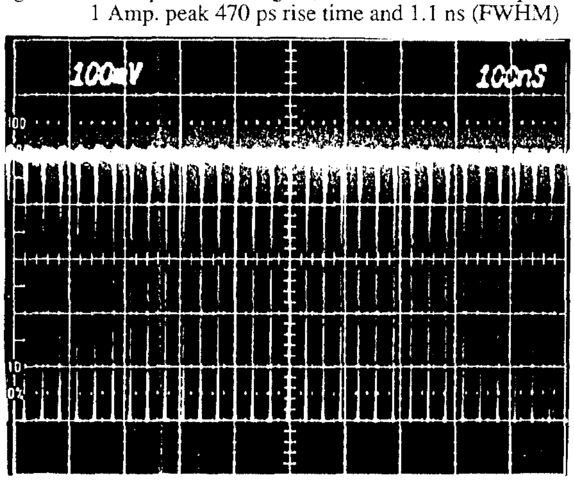

Fig. 7 A part of the micropulses train at 31.25 MHz, 1 Amp. peak, 12 μs duration.
Flat top stability < 0.5%

Fig. 7 shows a part of the micropulses train at 31.25 MHz. The flat top ondulation is lower than 0.5% on the 12 μs total duration.

The phase shift between the gun micropulses and the original 500 MHz from the RF subharmonic cavity is lower than 1°.

Aknowledgements

I am grateful to all the people of the CLIO team for their wide contribution in this project.

References

[1] Rapport CLIO LAL/RT 89-04 - February 1989.

[2] One nanoseconde pulsed electron gun systems Roland F. KOONTZ SLAC - PUB - 2261 February 1979.

[3] W.B. Herrmansfeldt, "Electron Trajectory Program" SLAC report 226, November 1979.