CLIO : Free Electron Laser in ORSAY

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SUMMARY.

A 50/80 MeV Linac devoted to an infrared (2-20μm) free electron laser is under design and going to be built in Orsay. The proposal was approuved an funding obtained at the end of 86. Several institutes are involved in this project called CLIO (Collaboration pour un laser à électrons libres infrarouge à Orsay) under the leadership of the LURE (Laboratoire pour l'utilisation des rayonnements électromagnétiques), the LAL (Laboratoire de l'Accélérateur Linéaire) being in charge of the electron linac and the CEA of the undulator. We present :

- a table of the main characteristics of the project
- a general description of the Linac
- the main components of the Linac
- the status of the project in june 88 and the estimated schedule.

I - INTRODUCTION.

CLIO is designed* to be a broadly tunable, medium peak power, infra-red Free Electron Laser which will be used as a light source facility as well as for FEL fundamental studies. It is driven by an S band RF linac whose characteristics must fit the FEL requirements.

I.1 FEL main features

. parameters of the optical cavity :	
– total length between mirors	4.8 m
– nb of ondulators	2(the 2nd tappered)
– individual ondulator length	0.96 m
– magnet type	permanent (Sm Co5)
– magnet periodicity (λ_o)	4 cm
– minimum gap (adjustable)	1 cm
– K parameter	0 to 2
. laser wave length range	2 to 20 μm
. peak power (micropulse)	10 to 100 MW
. peak power (macropulse)	up to 150 kW
. average power	10 to 100 W
. energy/macropulse	0.2 to 1.5 J
. small signal gain	≥30%
. spectral bandwidth	$3.10^{-4}.\lambda(\mu m)$
. build up time of the	
. laser oscillation	2 to 3 μsec
. efficiency : electron to laser beam	0.5 to 2%

I.2 Corresponding linac beam characteristics

. energy range	50 $\pm$ 20 MeV
. max. energy at vanishing beam	80 MeV
. micropulse length	10 to 15 ps
. macropulse length	up to 12 μs
. peak current (macropulse)	up to 300 mA
. peak current (micropulse)	up to 100 A
. electrical charge/micropulse	up to 1 nC
. time interval between adjacent micropulses	2,4,8,16 or 32 ns
. rep. rate (macropulses)	12.5,25 and 50Hz
. average beam power	up to 7.5 kW
. normalised ($x\beta\gamma$)emittance	150 πmm mR
. energy spread	$\pm$ .5%
. electrical charge/micropulse	up to 1 nC

II - GENERAL DESCRIPTION OF THE LINAC.

As shown on Fig. 1, the RF Linac consists of a :

- 100 kV gun
- 500 MHz subharmonic buncher
- 3 GHz fundamental frequency buncher
- 3 GHz travelling wave accelerating section
- set of solenoïdal focusing coils from the gun anode to the end of the accelerating section
- 2 x 30° transport system

The time structure of the beam is shown on Fig. 2
The 2 stage bunching process is schematically discribed on Fig. 3.

II.1 Operation

There are 2 main modes of operation :

1- The gun emits a "CW" beam during the 12 μs of the macropulse ; at the end of the bunching process, we get a train of one micropulse every 2 ns (1/6 of the fundamental frequency) with unavoidable parasitic bunches.

A gun current of 0.5 A is then sufficient to obtain 0.3 nC in the main microbunch.

* The Los Alamos [1] and Stanford [2] FEL experiences were greatly taken into account.

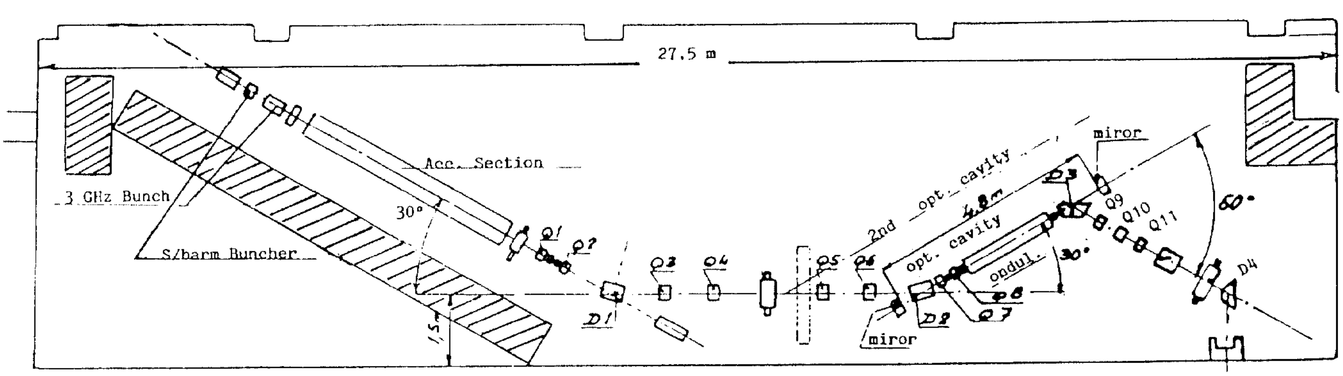

Fig 1 - Lay-out of CLIO

2- The gun is pulsed : it emits one 1 ns pulse every 4, 8, 16 or 32 ns during all the 12 µs macropulse in synchronism with the RF frequency

At the end of the bunching process, we get the corresponding required time structure. In order to obtain 1 nC/microbunch we need a peak gun current of 1 to 2 A.

The Linac beam energy is ajusted through the RF power feeding the accelerating sections.

The beam intensity is ajusted through the gun emission and repetition rate.

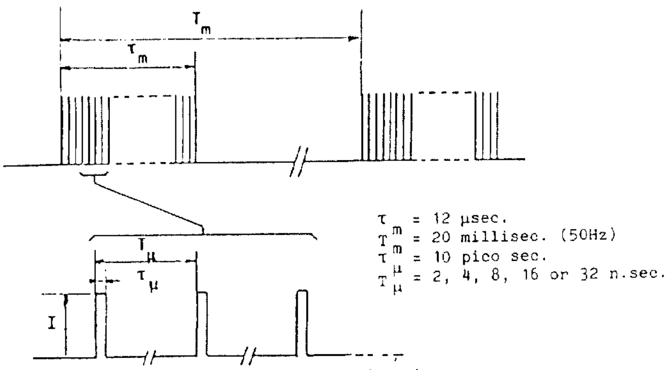

Fig. 2 - Time structure of the Linac beam

II.2 Beam dynamics

An extensive beam dynamics analysis by computer simulation using the code PARMELA (all the RF and static field components and the beam space charge are taken into account) has shown that one could easily reach :

. a bunch compression up to 1 nC in 10 ps (70% of the e^-)

. a normalised transverse emittance in each plane containing 90% of the $e^- \simeq 30\ \pi$ mm mR $\ll 150$ required one. As the emittance extension essentially comes from the bunching process, we can relax on the gun performance for which 15 π mm mR is low enough.

The transport system matches the Linac output in order to obtain a quasi parallel beam along the undulators with a waist as small as 1 mm in diameter at the center of the optical cavity even for large energy spreads, without disturbing the e^- time structure. So it is designed to be achromatic over a ± 3% momentum bandwith and quasi isochronous ($\Delta t \leqslant 1.5$ ps/%). The energy resolution is as good as 0.2% (useful for narrow band operation).

In addition, provision is made to allow the setting up of a 2nd optical cavity.

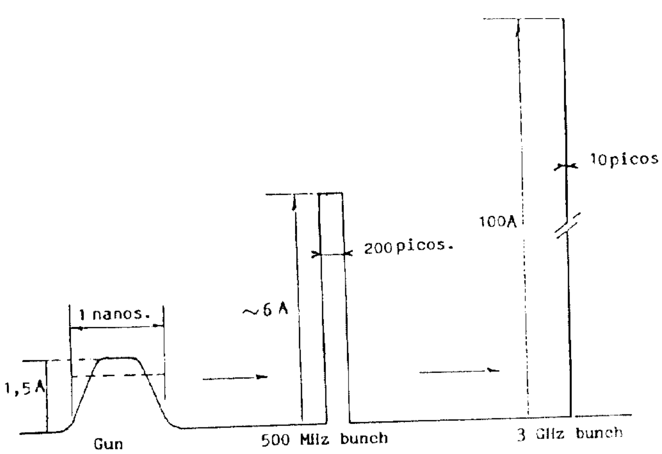

Fig. 3 - Bunching process

III - MAIN COMPONENTS OF THE LINAC.

III.1 The electron gun

The required performances may be obtained with a conventional triode gun close to the "model 5" SLAC gun *. So we started from the same grid/cathode set i.e the "Eimac Y 646 B" dispenser gun cathode; then we have worked out the design of electrode shapes using the "ETP Hermansfield code" of SLAC in order to get the smallest emittance. (Fig. 4).

For 90 kV and 2 A perveance limited, we obtain 2 π mm mR (norm.) very close to the cathode emittance alone. However for smallest currents injected by the grid cathode space the emittance grows, since the space charge factor of the beam is lower than the perveance of the gun. In addition we have roughly evaluated the grid lens effect and finally estimated a normalised emittance $\simeq 15$ πmm mR in the range of 0.5 A to 2 A.

Mechanically, the gun frame is designed to fit also another cathode "Eimac Y 796" which may be used in a further version of our FEL. The ceramic isolator is designed to withstand up to 200 kV DC. The cathode anode space is pumped down through a good conductance pipe by 60 l/s pump to a pressure of 1×10^{-9} Torr.

A counter-field coil located in the cathode plane produces a zero magnetic field at the cathode surface and then the magnetic field inside the gun increases lineary by 1 kGauss/meter.

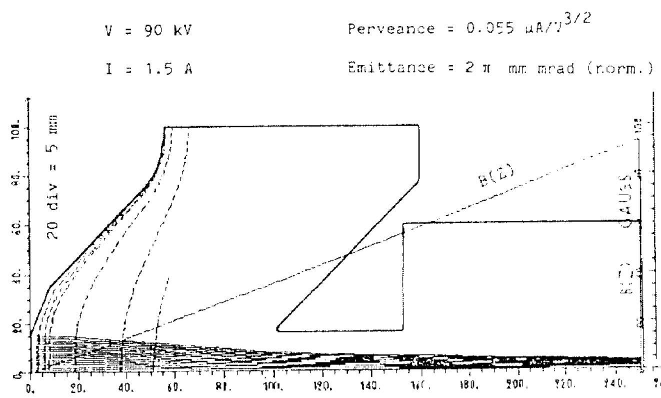

Fig. 4 Beam trajectories for perveance limited conditions

III.2 The gun pulser

The triode gun is driven by the cathode for the pulsed mode and by the grid for the "CW" mode, the bias being applied on the grid. A 500 MHz 2 W signal during 15 µs is carried to the HV deck through an isolated HF transformer made of two coupled loops of coaxial cable. A frequency divider controled from the ground level through optical links, elaborates the pulsed signal of - 0.6/0.8 ns every 4,8,16 or 32 ns which will be amplified up to -200V/1ns by a solid state amplifier of 50-500 MHz bandwidh.

With a cutoff voltage of 30 V and a transconductance of about 10 millimhos, we expect to get micropulse of 1.5 A peak/1 ns at the gun output.

Along the 12 µs, the residual macropulse slope is compensated for by an ajustable counter voltage slope applied on the grid.

In the case of a "CW" beam, we stop the cathode pulser, and switch on the grid pulser : we obtain a long 12 µs "CW" pulse with an adjustable flat top too.

* (which has already been used for 2 years at Orsay).

The amplifier and power supplies, attached to the HV deck are controled through optical links from the ground level.

III.3 The subharmonic buncher

This prebuncher is a stainless steel re-entrant cavity operating at the 1/6 th subharmonic of the accelerating structure frequency. It is chosen so that the 1 ns gun pulse extends roughly within a $\pm$ 90° phase spread in the prebuncher and the buncher after the first compression step. The main parameters of the cavity are :

frequency	: 499.758 MHz at 30°C
Q_o	: 2800
R/Q	: 140
operating gap voltage	: 30 kV

The cavity is fed by a 25 kW pulsed transmitter. By adjusting the amplitude and phase of the gap voltage in association with the tuning plunger position, one can cope with any beam intensity.

III.4 The fundamental frequency buncher

The buncher is identical to the LIL (CERN) one i.e. a copper triperiodic, S band standing wave structure. It is composed of 3 wavelengths, slightly matched to the beam velocity (0.92, 0.97 and 1 λ).

The main parameters of the buncher are :

frequency	: 2998.550 at 30°C
Q_o	: 13000
loaded filling time	: 0.78 µs
useful length	: 0.35 m
operating power	: 1.5 MW
no load energy	: 4 MeV
beam loading	: 5.8 KeV/mA

III.5 The accelerating section

The section is a constant gradient S band travelling wave disk-loaded structure [3].

This section was developped by LAL for LIL (CERN).

The main parameters of this structure are :

frequency	: 2998.550 MHz at 30°C
length	: 4.5 m
mode	: 2 π/3
average shunt impedance	: 64 MΩ/m
Q	: 14000
c/vg,	: from 41 to 137
attenuation	: 7.2 dB
input power	: 25 MW
filling time	: 1.35 µs
no load energy	: 78 MeV
beam loading	: 0.9 MeV/10 mA
nominal energy at 250 mA	: 50 MeV

The section is surrounded with a set of solenoïdal coils which give a continuous axial field adjustable up to 0.2 Tesla.

III.6 The main RF power source

The 3 GHz buncher (1.5 MW) and accelerating section (25 MW) will be fed by a 28 MW, 12 µs klystron. Such a tube is not commercially available so far but several existing ones, slightly upgraded, should reach one required performances.

The G.E./CGR-MeV company, is in charge of the corresponding high power, high stability modulator which is designed to fit the following main specifications.

H.V. pulse:
- flat top length : 12 µs
- residual ondulation : 0.5%
- residual slope : 0.1%
- amplitude jitter : 0.1%

Power : peak 75 MW, average 60 kW

III.7 The beam transport system

There are essentially 2 magnets which bend the beam in the same direction. This set up gives a intermediate image at the center of the transport where the dispersion is maximum allowing a very good energy resolution. In addition its symetry forces to zero most of the 2nd order disturbing matrix coefficients so that the beam size is kept small in the undulators up to very large energy spreads. In order to allow enough room for a 2nd optical cavity and to improve the energy resolution, the 2 magnets are located far from each other so that a quite large number of quadrupoles is needed.

Such a system is not strickly isochronous.

$$c\Delta t = \frac{\alpha^3}{3} R \frac{\Delta p}{p}$$

In order to stay within the tolerances of 1.5 ps/% the bending angle α is kept small (30°), as well as the magnet radius R (0.56 m).

IV - STATUS OF THE PROJECT AND ESTIMATED SCHEDULE.

The studies of the injection, beam optics and of the main components are achieved, several others such as accelerating section, modulator, gun and its pulser, 500 MHz transmitter are being carried out in parallel with the undulator.

The first 80 MeV e^- beam is scheduled in the middle of 1990 and the laser would operate by the end of 1990.

References :

[1] R.W. WARREN et al., "The Los Alamos Free Electron Laser : Accelerator performances", Nucl. Inst. & Meth. - A 237, pp 180-186, 1985.

[2] S.V. BENSON et al., "Status Report on the Stanford Mark III Infrared Free Electron Laser" - Proceedings on the ninth international FEL conference, Williamsburg, Sept 87.

[3] G. BIENVENU et al., "Accelerating Structure Developpments for the LEP Injector Linac (LIL)" - Proceedings of 1984 Linear Accelerator Conference - p 463 - Darmstadt, May 84.