Optimisation of the FEL CLIO Linear Accelerator

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Abstract

CLIO (Collaboration for an Infrared Laser at Orsay) is an FEL user facility at the LURE Laboratory, ORSAY, France. Since the first oscillation in January 1992, CLIO has improved its performance. As the laser quality closely depends of the linac's stability, the accelerator team has undertook some improvements, especially in the RF devices such as amplitude feedback, phase feedback, temperature stability. These improvements and their effects on the laser are presented.

1. INTRODUCTION

The CLIO laser, started in 1987, yielded the first laser beam on January 1992 at 5 µm. Two years later the spectral wave length range spans 1.8 to 17.5 µm with a micropulse peak power of about 30 MW, 5 ps.

About ten user groups are performing experiments on CLIO each year, taking advantage of the unique characteristics of this FEL, especially the adjustable frequencies of micropulses that permits one to keep the peak power constant while varying the average power.

1.1 Main laser beam characteristics achieved

The main characteristics achieved by the laser are summarized in Table 1.

Table 1
FEL measured features

Spectral range	1.8 to 17.5 µm
Peak power	up to 30 MW
Average power	up to 10 W (250 MHz, 50 Hz)
Macropulse width	9 µs
Micropulse width	0.5 to 5 ps
Spectral width $\Delta\lambda/\lambda$	0.3 to 5 %
Spectral stability	0.2 %
Micropulse interval	4, 8, 16, 32 ns
Macropulse repetition rate	6.25, 12.5, 25, 50 Hz

The laser quality i.e. the power and wavelength stability obviously depends of the electron beam stability from the S-Band Linac. And among the differents parts it is the RF devices which are the more important factors. Fig. 1 shows a layout of the accelerator (the beam transport line to the undulator is not shown).

2. THE ACCELERATOR

2.1 Main electron beam characteristics achieved

Table 2 summarizes the measured electron beam characteristics. For a more detailed description of the accelerator see [1] [2] .

Table 2
Main electron beam characteristics reached

Energy range		30 to 60 MeV
Energy spread		< 0.75 % FWHM
Micropulse	charge at the gun exit	1.2 nC
	into undulator	0.6 nC
	length	5 - 12 ps
	peak current	50 - 75 A
	interval	4 - 8 - 16 - 32 ns
Macropulse	length	11 µs
	repetition rate	6.25 to 50 Hz
	average beam power	up to 5 kW (50 Hz)
Emittance 4 $\pi\beta\gamma\sigma\sigma'$		150 π mm mrad

2.2 Improvements on the accelerator

In this S-Band accelerator (3 GHz), the RF devices are divided into two main parts. The gun and the subharmonic buncher cavity (SHB) work at 500 MHz and then the Fundamental Buncher (F.B) and the accelerating structure work at 3 GHz. The phase stability between the gun and the SHB is not crucial because the microbunches are made by velocity modulation around the zero of the electric field at 500 MHz into the SHB cavity while the gun pulses have a gaussian-like temporal distribution 2 ns long at the base and nearly 1 ns FWHM. On the other hand the phase between the SHB cavity and the FB is more important. Indeed after the drift-space of .5 m the bunch's width and phase strongly depends of the field intensity and phase into the SHB. So we have stabilized the RF field intensity into the SHB to within $\pm 1.10^{-3}$.

Another problem is the adjustment of the phase between the FB and the accelerating structure. Because of the high RF power (20 MW) in the accelerating structure, the waveguide phase-shifter is in the arm that feeds the buncher where the RF power is only 1 to 2 MW. With this arrangement the phase adjustment is not easy to do because we have then to readjust all the other phases, which makes the tuning procedure very lengthy. So, we have fixed this phase by a feedback loop with the pilot reference at 3 GHz. And finally we have stabilized the temperature of these RF components.

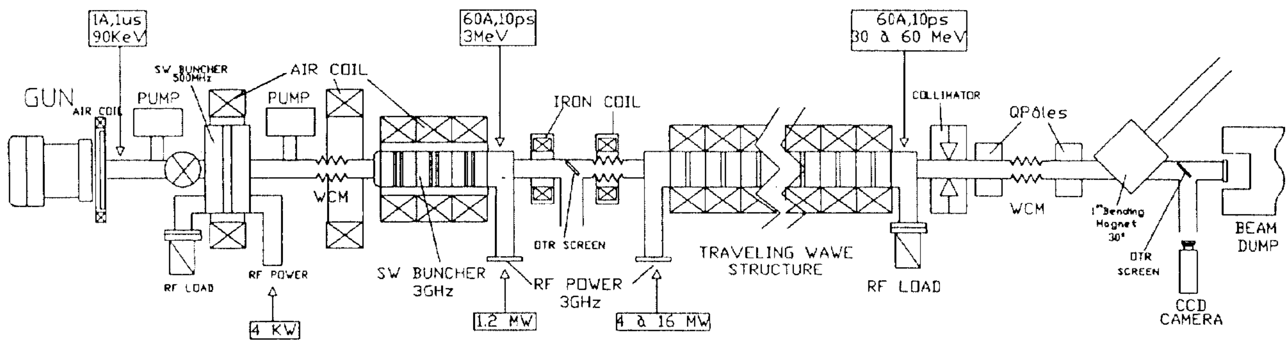

Figure 1. Layout of the CLIO accelerator

2.3 Temperature optimisation

The laser wavelength varies as the inverse of γ^2 (Lorentz factor of relativistic electrons) and the laser gain as the peak current of electron microbunches. We see that both the energy and current must be as stable as possible. If the temperature of the accelerating structure varies, the detuning modifies the phase velocity of the accelerating wave. The bunches shift from the creast of electric field. The central energy decrease and the energy spread increase drastically. For example $\Delta\theta = 0.25°C$ leads to a full phase shift of 6° @ 3 GHz along the structure and increases the energy spread for a 10 ps bunch by a factor 2. Detuning of the buncher leads to poor bunching and decreases the beam peak intensity. In the SHB cavity, because of its low Q, the temperature has a small effect.

The temperature is stabilized by a water cooling system where the hot water is evacuated through a controled valve actuator, and where the cold water (demineralized water at 28°C) directly arrives into the circuit.

There are two independent cooling systems one for the SHB cavity and FB at 32°C and the other for the accelerating structure at 30°C.

The previous regulators (home made) were not accurate enough to guarantee $\Delta\theta < 0.1°C$. We have replaced all the temperature pick-ups by standard Pt 100 and bought a new temperature regulator made by Eurotherm-Automation. This double regulator, remote controled by software, allows several configurations specially few set of PID parameters that are very interesting to control a non linear process. We also have installed two water tanks in the entrance of the cold water that smooths their quick temperature fluctuation. In these new conditions we get a stability of ~ 0.05°C peak-peak both in the FB and accelerating structure. So that a negligible phase shift occurs.

2.4 The subharmonic buncher

The subharmonic buncher is a stainless steel reentrant cavity in the mode TM010 at 499.758 MHz i.e. the 1/6th subharmonic of the fundamental frequency of the accelerating structure. A plunger compensates for detuning due to the beam loading induced by the beam already bunched at the gun.

In order to economise on the RF power from the amplifier and cancel the reactive impedance seen by the source, one detunes the cavity by an amount.

$$\Delta f = \frac{fo}{2Q} \times I_F \times \frac{R_{SH}}{Vcav}$$

Where Q is the loaded quality factor ~ 990.
I_F is the 500 MHz component of the beam current.
R_{SH} is the shunt impedance ~ 100 kΩ.
Vcav the voltage across the gap.

For example :

We need 30 kV across the gap (routine value).
With a beam current of 1 A 1 ns at 250 MHz.
IF ~ 200 mA @ 500 MHz

Finally : Δf = 168 kHz

In the above conditions we have measured 160 kHz.

In the routine for each repetition rates 250, 125, 62.5, 31.25 MHz of the microbunches, the software adjusts the plunger to a predetermined value

As the field into the cavity is the vector sum of that from the generator and that induced by the beam, its intensity and phase are tied. So it was not easy to adjust the phase without changing the intensity. We decided to keep constant the intensity in order to get the same velocity modulation that always produces the optimum bunching after the same drift space. Then, we have made a feedback on the field amplitude. A small loop into the cavity monitors the field. After detection, a sample and hold gate stores the level between the macropulses, then a differential amplifier compares with the reference level and drives the RF controled attenuator. The transfer function of the loop was studied for adjusting the gain in order to get the best response around the working point. Moreover the stability from macropulse to macropulse has been improvided by a factor 2. The stability is within $\pm 1.10^{-3}$.

Fig. 2 shows the feedback design.

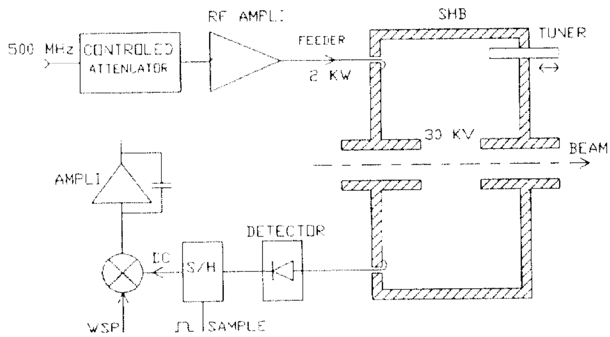

Figure 2. Level feedback of the SHB cavity

2.5 Phase feedback on the Fundamental Buncher

An RF phase feedback loop between the Fundamental Buncher and the 3 GHz reference has been recently achieved and expected to cancel the slow phase shift occuring a few hours after the accelerator starts. This phase shift comes from the temperature variation of various components. The feedback also makes easy the phase adjustements as already explained above.

The FB phase is fixed by the feedback loop. Then the accelerating wave phase changes when we act on the FB waveguide phase-shifter as if this was in the accelerating structure branch. So we get a "virtual power phase shifter". Fig. 3 shows the RF distribution.

A mixer, used as a phase detector, compares the incident wave going into the FB to the cw 3 GHz reference. The detected signal is held by a sample and hold gate and acts on a varactor microstrip phase-shifter through an amplifier and corrector network.

This new device works perfectly and allow us to adjust the final energy without changing the bunch quality. But there is still a very slow shift between the 500 MHz branch and the 3 GHz branch of 40° @ 3 GHz over 6 hours. We are still working on this.

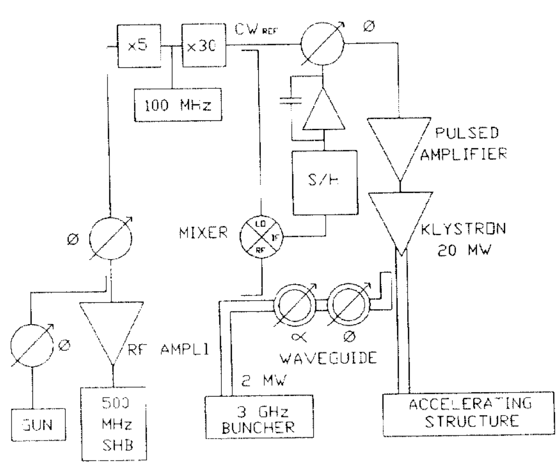

Figure 3. Virtual accelerating structure phase shifter

2.6 PFN adjustment

A new PFN adjustment was performed by observing the RF phase between the output and input of the klystron. This method is much less noisy than to observe the voltage pulse itself and allows fine tuning of each of 58 PFN cells. Fig. 4 shows the best tuning we have obtained with 0.54° @ 3 GHz peak-peak, this means $\Delta V/V = 1.13\ 10^{-3}$ on the flat top of the cathode pulse. This result corresponds to an energy stability of $\Delta\gamma/\gamma = 5/4\ .\ \Delta V/V = 1.4\ 10^{-3}$ and to a laser wavelength stability $\Delta\lambda/\lambda = 2.8\ 10^{-3}$. In the lower part of Fig. 4 the wavelength evolution is shown ; up to 7 µs the spectral wavelength is constant but during the PFN oscillations the spectrum width oscillates at the same frequency. However the central wavelength remains constant within about 0.1%. Wavelength drifts of typically ± 0.25% are seen. Nevertheless this new adjustment has strongly improved the behavior of the spectral evolution during the laser macropulse and combined with the best RF stability has allowed to get up to 10 W of average laser power (see Ref. 3).

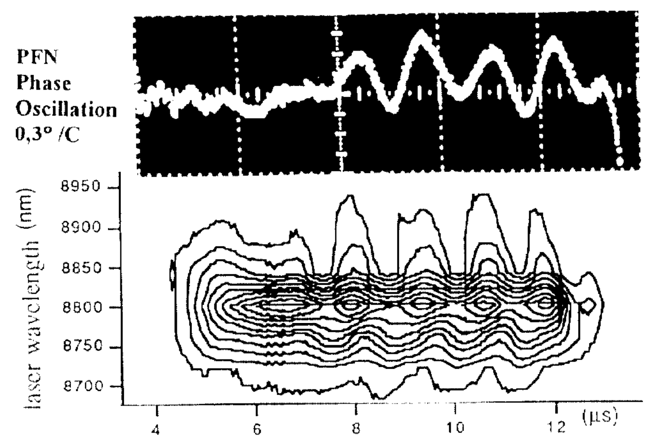

Figure 4.
Correlation between phase oscillation in the PFN and laser wavelength

3. FUTURE

In order to extend the spectral range towards 40 µm we plan to change the period of the undulator, and install a larger pipe in order to avoid losses. As we will have to decrease the lowest energy of the electron beam down to 20 - 25 MeV, we need the same RF power in the Fundamental Buncher and even need to increase it to improve the bunching quality. So we plan to change the RF coupler feeding the FB from -9 dB to -6 dB. At the end of the accelerator the beam emittance will be automatically measured and permit us a systematic study of the beam peak intensity influence.

4. REFERENCES

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Companion paper in this conference to be published in proceedings.