Short Pulse Generation with the CLIO FEL

F. Glotin, J.-M. Berset, R. Chaput, D. Jaroszynski, J.-M. Ortega and R. Prazeres
L.U.R.E., bât. 209D, 91405 ORSAY Cedex

Abstract

Laser pulses of less than 500 fs duration (FWHM) have been produced using the CLIO free-electron laser, at a wavelength of $\lambda = 9$ µm. Since the linac stability has been improved, short optical pulses are now produced by running the CLIO linac in the standard configuration.

1. INTRODUCTION

1.1. *CLIO*

CLIO is an Infrared Free-Electron Laser (IFEL), designed to operate as an user facility at the L.U.R.E. laboratory, situated at Orsay in France. The first laser beam was delivered in January 1992. Since then, about ten user teams have obtained and published originals results in various fields [2], taking advantage of the main characteristics of the laser: continuous tunability in a wavelength range 1.8 to 17.5 µm, and peak powers up to 30 MW, useful for non-linear optical studies.

The main components of CLIO are an S-band linac, a near-isochronous deviation, and an optical cavity, including a 48-period Halbach type undulator (1.92 m long). The linac itself includes a thermionic gun, followed by a subharmonic buncher cavity (500 MHz), a standing-wave buncher (3 GHz) and a travelling-wave accelerating section (3 GHz). The electron bunches enter the latter one with an energy of 4 MeV, and are then boosted up to the 30-60 MeV range.

The electron micropulses, a few picoseconds long, are generated at a variable frequency between 31.25 and 250 MHz. A train of micropulses constitutes a macropulse, which is 10 µs long and can be generated similarly at a frequency between 6.25 and 50 Hz.

A more detailled description of CLIO can be found in various publications and reports [1,2,3].

1.2. *Temporal structure*

In the course of 1993, we have performed a length measurement campaign for both electron and laser pulses [6,7,11].

The longitudinal electronic density profile of the electron bunches has been deduced from their energy spectra, after they have been dephased relatively to the HF accelerating-wave crest in the section. At 40 MeV, this leads to a FWHM of about 10 ps and a peak current of 70 A.

For such an electron beam, the laser pulse width has been measured at $\lambda = 8$ µm, at different positions on the so-called detuning curve. This curve show the laser power evolution versus the optical cavity length. At a cavity length such that the round-trip time of a laser pulse is close to the time interval between electron pulses, the laser power is maximum: the optical pulse length has been observed to have a minimum (about 1.5 ps FWHM in our case), and a large spectral linewidth (1-2%). As the cavity length is shortened, the pulse length becomes longer (up to 6-7 ps) and the laser linewidth decreases (0.4%). This behaviour is well understood in FEL physics [9]. The measurements have been carried out using a Michelson interferometer and a frequency-doubling crystal, providing intensity autocorrelation curves [5]: a mirror in one of the interferometer arm is motorized and computer controlled, and can be moved to vary the overlap between the laser pulses leaving the Michelson.

2. CHIRPED ELECTRON BUNCHES

In view to produce shorter laser pulse, useful for certain applications, we have tried to generate laser pulses chirped in frequencies. These pulses could thereafter be time-compressed using dispersive devices, following usual methods for femtosecond pulse generation in conventional lasers. It has been suggested in the literature [4] that electron bunches similarly chirped in energy could be relevant to generate such optical pulses, as the laser radiated wavelength scales as $(2\gamma^2)^{-1}$, where γ is the relativistic factor of the the electrons.

Unfortunately, some simulations we have performed showed that, at least in the CLIO case, the time-frequency relationship inside the laser pulse becomes distorted when saturation occurs, leading to pulses unsuitable for compression.

However, we have succeeded in lasing with electron bunches chirped in energy, which have been produced by dephasing them along the HF accelerating-wave in the section: this is indeed a scheme similar to the one used to estimate the bunch length mentioned previously. In this configuration, the laser pulse width appeared to be substancially shortened, without any need of dispersive devices [6,7,8]: widths of typically 700 fs FWHM have been measured.

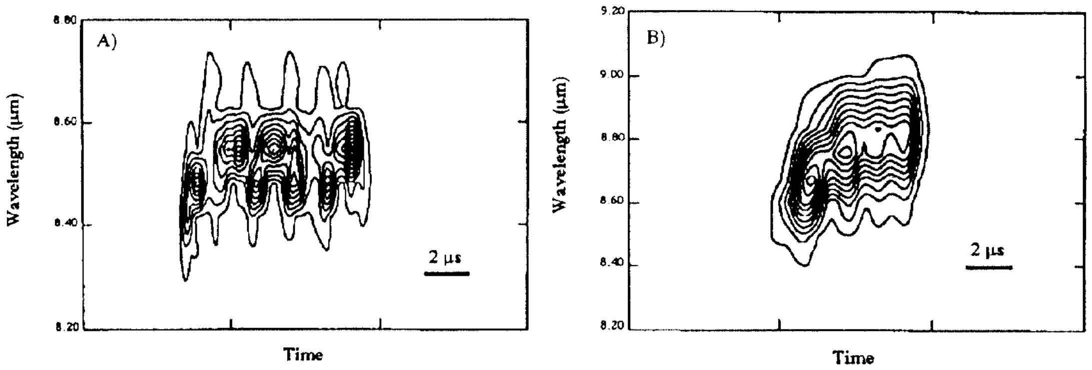

Figure. 1: Spectral evolution of the laser with time, inside the 8 µs long macropulse, before the PFN improvement. A) Normal operating conditions, optical cavity slightly detuned. B) Operation with chirped electron bunches.

This shortening effect was therefore assumed to come from the energy slew imposed on the electron bunches. However, and as discussed below, sub-picosecond laser pulses have been generated since with a normaly operating machine. The overall accelerator stability has been improved, and particularly by carefuly adjusting the Pulse Forming Network (PFN) of the klystron modulator [3]. As a consequence, this has leaded to a smoother spectral evolution of the laser inside the macropulses, allowing the optical spectrum to grow larger, and the corresponding optical pulse lengths to diminish.

Therefore, the reduction in the optical pulse lengths observed with electron bunches chirped in energy is now assumed to have come from a correcting action of the PFN flaw. This appears on Fig. 1, where two 3D plots of the temporal evolution of the laser spectrum inside a 8 µs macropulse are compared. Fig. 1.A. corresponds to a normal macropulse before the PFN correction in September 1993, and for an optical cavity slightly shortened relatively to the optimal length for maximum power. The nefarious action of the PFN is manifest there, as it makes the laser wavelength jump between two values with a periodicity which can be traced back to it. However, the smooth evolution displayed on Fig. 1.B. corresponds to similar conditions, but with chirped bunches. The larger spectral envelope there, with no sign of sidebands development, is in good agreement with the shorter laser pulses observed.

3. RECENT RESULTS

Some new measurements have been performed recently (April 1994), at wavelength $\lambda = 9.2\,\mu m$ and with an electron beam of 40 MeV energy. Since the accelerator stability has been improved, the laser spectra for maximum power have been observed to be larger than before: about 5-6% FWHM instead of 2% previously. Futhermore, it must be noted that such large and quite smooth spectra occur on the detuning curve over a range futher away than the one where sidebands appears in the spectrum, due to the well-known synchrotron oscillations effect [9]. Spectral and autocorrelation measurements are performed by averaging over the whole macropulse.

Fig. 2 shows some frequency and autocorrelation spectra recorded in these conditions, for a repetition rate of 31.25 MHz for the micropulses and 25 Hz for the macropulses. For a low total average power extracted of the optical cavity (300 mW), the frequency spectrum is narrow and the laser pulses long. Experimental data in this case are not displayed here. At a higher power (400 mW), achieved by lengthening the cavity, synchrotron oscillations manifest themselves as can be shown on Fig. 2.A. and B. For maximum power (750 mW), the peaks in the frequencies domain merge to give the spectrum C). For such a spectrum, the interferometric autocorrelation pattern D) is very narrow: while averaging over the interference fringes, one obtains a 550 fs FWHM. The actual laser pulse width can not be deduced directly from this measurement without making some assumption on the pulse shape [5]. However, this width is never larger than that derived from the autocorrelation spectrum, at least for simple shapes. Assuming a Gaussian, one obtains a value of 390 fs FWHM for this particular spectrum. Similar measurements lead to an average value for such short pulses of 450 ± 100 fs.

However, these results are recent and their reproducibility must be tested furthermore. In particular, one must verify that there are no other laser sub-pulses following the first one. This seems unlikely on examination of our complete set of spectral and autocorrelation patterns. The smooth shape of the frequency spectrum also indicates no temporal sub-structure But as the crude spectrometer used to monitor the spectrum shape in real time allows a poor resolution (0.9%), this point can not be emphasized.

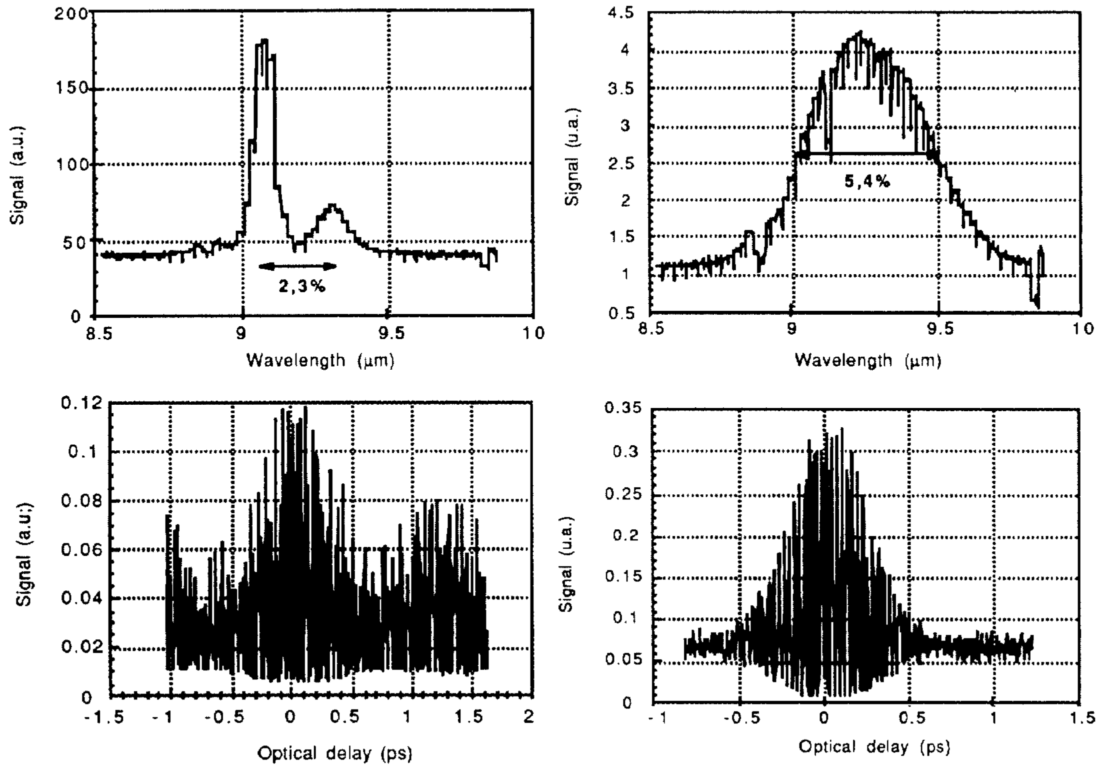

Figure 2. Frequency and autocorrelation spectra recorded recently at $\lambda = 9.2\ \mu m$, for different cavity lengths and high intracavity power; A-B) Well-defined sideband and corresponding modulation in the temporal domain; C-D) At maximum power.

4. DISCUSSION AND CONCLUSION

Since the CLIO accelerator stability has been improved, larger spectral widths have been achieved (5% FWHM), and laser peaks of subpicosecond duration (450 fs FWHM) have been measured by an autocorrelation technique. These measurements were carried out at a wavelength $\lambda = 9.2\ \mu m$.

Very first hypothesis which can be advanced to explain how short such pulses can be, compared to the 10 ps long electron bunches, are the following:

- They are indeed some other laser peaks further away of the main one, which have not still been detected.
- The effective electron bunch length is reduced. This can happens because this bunch presents a relatively sharp peak [6,7], and because the laser gain depend both on the electronic density and on the cavity length. Thus, it must be possible by adjusting this last one to keep the optical gain high enough for the laser on a relatively small part of the electron bunch.
- Dispersion in the optical cavity acts to suppress or compress the optical pulse as it develops towards saturation [10].

Beam time will be dedicated in the coming months to study this effect. Simulations are also being performed, including dispersion inside the optical cavity.

5. REFERENCES

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