PERFORMANCE OF THE FERMI FEL PHOTOINJECTOR LASER*

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Abstract

The photoinjector laser system for the FERMI FEL has been installed at the ELETTRA laser laboratory. It is based on a completely CW diode pumping technology and features an all-CW-diode-pumped Ti:Sapphire amplifier system, a two stage pulse shaping system, a time-plate type third harmonic generation scheme and aspheric shaper based beam shaping. The paper will present experimental results describing the overall performance of the system. The data demonstrates that all the initially set parameters were met and some largely exceeded. We present what is to our knowledge the first direct measurement of the timing jitter added by a Ti:Sapphire amplifier system and show that for our case it is below 10 fs.

INTRODUCTION

The photoinjector laser (PIL) is known to be one of the very important sub-systems for all single-pass UV and X-ray FELs. The charge and quality of the electron bunch created at the photoinjector (PI) affect dramatically the operation of the FEL and can be a strong limitation in obtaining the expected FEL performance. This is especially true for the challenging projects that are now in construction phase (like LCLS, SLAC, European XFEL). A lot of attention has thus been devoted previously for studying the optimum parameters of the PIL. It is now well accepted that the UV beam should have a nearly flat top spatial profile, while the optimum longitudinal (temporal) shape may vary [1-3]. In addition, laser parameters like energy and beam pointing that may seem easier to control, have also to be very carefully optimised. The overall system design appears to be more difficult in the case of copper photocathode, because of the required very high UV energy (~0.5 mJ for extracting 1 nC). The implementation of beam and pulse shaping techniques at these energy levels in UV is quite challenging. In this paper we describe the schemes and technologic solutions developed at Elettra for the FERMI PIL. As it will be seen the system fully meets and in some aspects exceeds the requirements.

MAIN SYSTEM DESIGN

As it has already been discussed in earlier papers [4], the only laser technology that can meet all the PIL parameters requested for copper photocathode, and is enough mature and reliable, is the one based on Ti:Sapphire as an active material and regenerative amplifier/multipass chirped-pulse amplifier design. The amplifier system described here is a custom system constructed by Coherent Inc. This is in fact the first amplifier system of this type, reaching an energy level above 18 mJ in the infrared, with the use of entirely CW diode pumping technology, which is the base for the extremely high UV energy stability reported below. The amplifier design is shown on Figure 1.

As it is seen, the seed coming from a Ti:Sapphire oscillator (Mira), is stretched and amplified to a mJ level in a regenerative cavity, after which it is further amplified in two two-pass amplifier stages. Each of these is pumped by up to 45 mJ from two Evolution HE Nd:YLF Q-switched pump lasers. As mentioned above, they are pumped by diodes in CW. Table 1 summarizes some of the main laser parameters.

Parameter	Specs	Measured
IR output energy	> 18 mJ	> 18 mJ (~15 mJ in operation)
Pulse duration (Gauss.fit)	<100 fs	~90 fs
Center WL	780+/-5 nm	~783 nm
M^2 value	$M^2_{x,y}$<1.5	M^2_x~1.27, M^2_y<1.17
UV energy before shaping	>2 mJ	>2.3 mJ
Short term energy stability UV (500 shots), RMS	<3%	<0.6%
Long term energy stability UV (8 hours), RMS	<3%	<0.8%
Beam pointing stability	<10 µrad	<5 µrad
Timing jitter (10 Hz-10MHz), RMS	<350 fs	<180 fs

Table 1: Main laser parameters , left- specified, right-measured

We note that the system is capable of delivering >18 mJ energy per pulse in IR, however the reported 2.3 mJ of UV energy is obtained at ~15 mJ in the IR. This regime is preferred for everyday operation because of lower diode current (~19A) and also lower load on the optical components. Conversion efficiency to third harmonic (261 nm) is about 15% and has been fixed after careful balancing of spot-size and pulse duration. Both interferometer like and 'time-plate' designs of the THG unit have been tested with similar results. However, in the latter we have observed a deterioration of the calcite plate which pre-compensates the group velocity mismatch, so at present the interferometric version is in operation.

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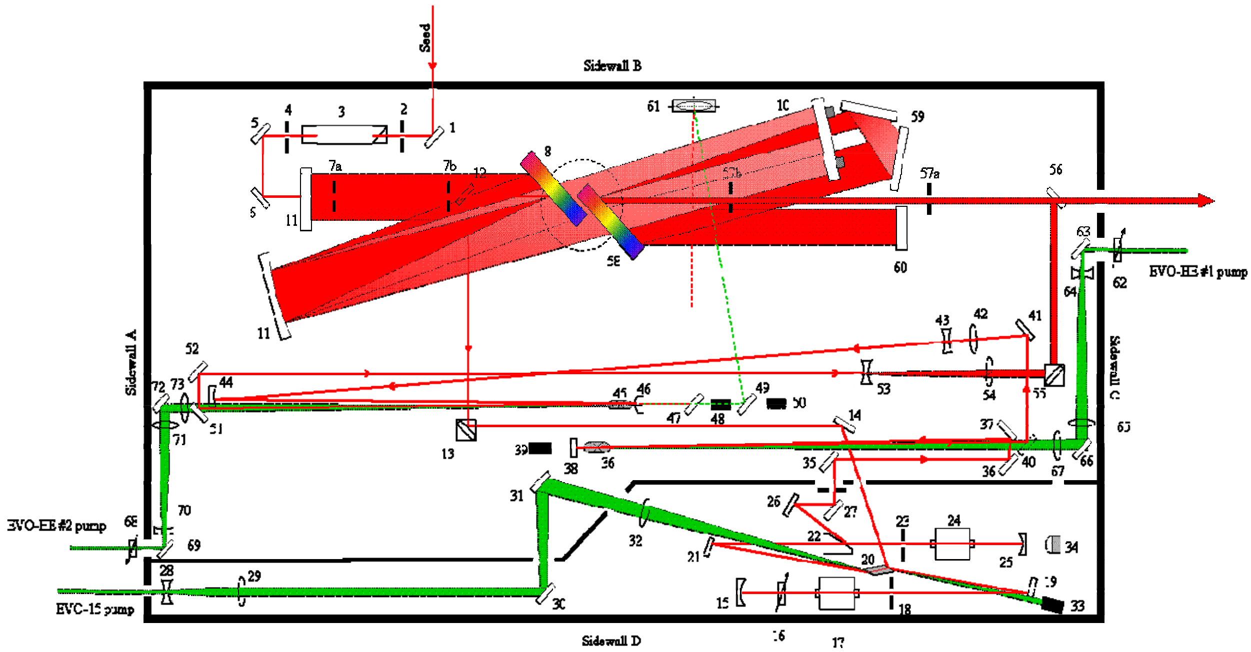

Figure 1: Amplifier design.

TIME SHAPING

The concept chosen for our time-shaping system has been already described previously [4]. In brief, it implements a two-step hybrid shaping system in which a preliminary shaping is performed in IR by an acoustooptic dispersive filter (DAZZLER , Fastlite), and the final shape and duration of the pulse are done in the UV in a Fourie system. In principle the DAZZLER allows both amplitude and phase modulation [5]. We note that the amplitude shaping done by the DAZZLER is partially lost in the amplification process due to the strong ‘red’ shift of the amplified spectrum with respect to the seeding one. For this reason the DAZZLER alone is not sufficient for producing the required pulse shapes. .

The main temporal shaping is thus performed in UV by the 4-f system shown on Fig.2. The UV pulse coming from the harmonic generation system enters a Fourier-shaping scheme consisting of the grating G1, folding mirror M1, lens L, deformable mirror (DM) and retro-reflecting mirror M2. The modulation is mostly performed by the DM (OKO Technologies). The particular mirror used is a custom made dielectric plate (HR at 260 nm) glued on a 20 piezo transducers (2lines of 10), each of them can be moved by up to 10 micron. As it is seen from the figure we use a configuration where the mirror is used at a large angle, thus increasing the number of useful actuators and the induced phase difference. In alternative configuration, a longer focal distance lens and DM at normal incidence can be used. The DM is used for providing mostly the high order dispersion terms, while half of the large second order dispersion term giving the final (several ps range) pulse lengthening is given by the

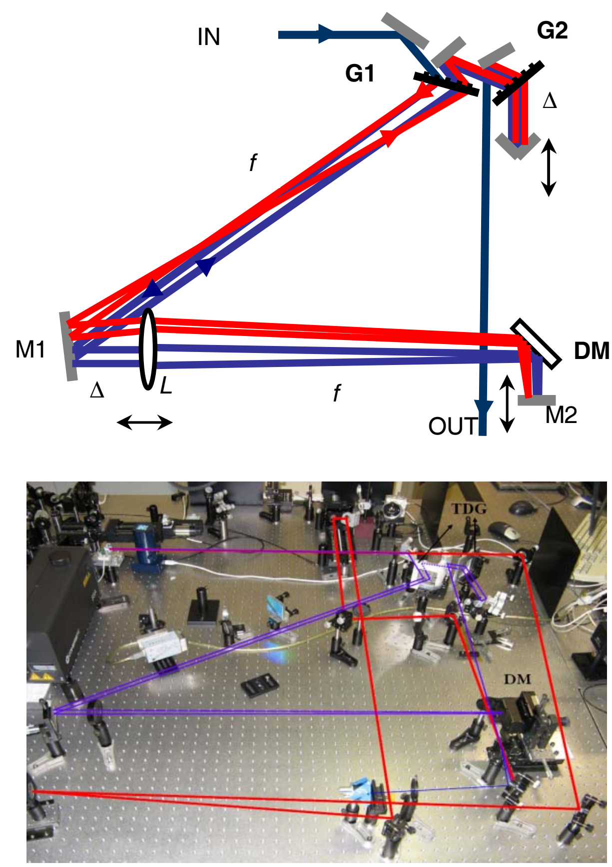

Figure 2: UV pulse shaping optical scheme (up) and photo of the setup (down).

off-focus distance Δ of the grating with respect to the front Fourier plane. The second half of the required group velocity dispersion (GVD) is provided by the double passage through the grating G2, which is also used to cancel the residual spatial chirp introduced by the shaper. The pulse length can be changed by changing Δ in both the shaper and stretcher and respectively adjusting the shape of the DM.

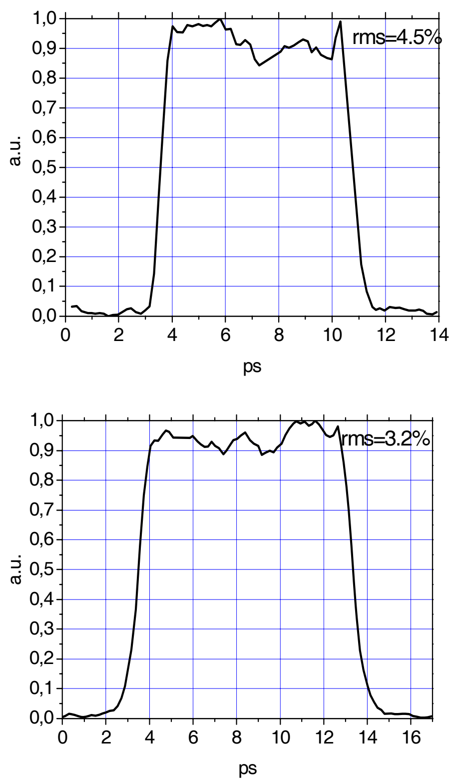

Figure 3: Flat-top pulses with duration of 6 and 10 ps produced using phase modulation by the DM.

Typical examples of the commonly requested flat-top type temporal profile are shown on Figs5. The flat-top duration could be made even longer, up to 15 ps, with the expense of increased modulation (~7% RMS) and fall time (~ 2ps).

As mentioned above, in the case of FERMI a nearly quadratically increasing ramp, as shown on Fig.4 a, is required [3], so the system has at present been optimized for generating such a profile. Fig. 4b presents typical pulse profile measured by cross-correlating the UV pulse with an IR pulse using down-conversion in a 250 micron thick BBO crystal. It was possible to change the duration of the ramp by adjusting the UV stretcher length. For small duration changes the pulse shape was not strongly affected, so no other adjustments were needed. For larger (i.e. more than 2 ps) duration changes, an additional adjustment of the piezo-mirror was necessary.

The transverse shaping of the UV beam is performed by a commercial asperic beam shaper (Moltech). After a proper adjustment of the input Gaussian beam dimension the shaper produces a flat-top distribution which then is relay-imaged on the cathode by the beam transport system. Typical_results at the output of the shaper and after a Relay imaging is shown on Fig.5, left and right, respectively.

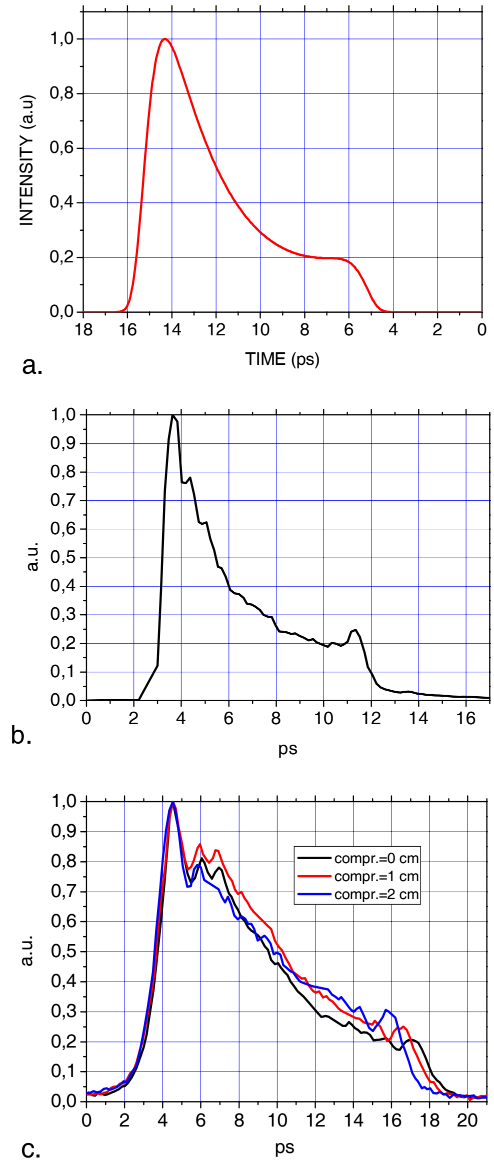

Figure 4: Increasing ramp pulse shapes, a-plot of the required pulse shape; b- cross-correlation trace of the obtained UV pulse; c- pulses of variable duration obtained by adjusting the compressor

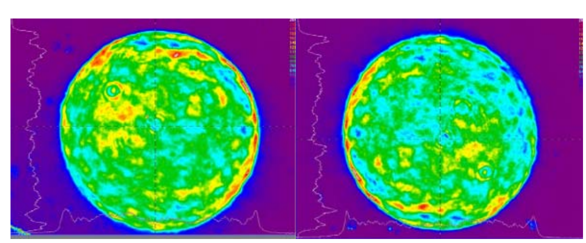

Figure 5: Images of flat-top UV beam after beam shaper (left), and after Relay imaging (right)

TIMING JITTER

The initially requested timing jitter for the FERMI PIL was initially set conservatively at 350 fs RMS , taking into account simulations that were performed at Elettra, as well as the best specs of commercial Ti:Sapphire oscillators. It was expected that the actual system performance will exceed the specs and this was confirmed by the measurements. First, the phase noise of the oscillator locked to an external low noise RF generator was measured. Integrating this curve in the range 10Hz-10MHz an RMS timing jitter of about 180 fs was obtained (blue curve on Fig.6). The red curve on the same graph shows the result of the same type of measurement done using a commercial fibre laser (Menlo Systems). It is seen that, if needed, jitter could be reduced by a factor of two if the latter (after frequency doubling) is used for seeding our amplifier system. At present, however, the jitter performance of the Ti:sapphire oscillator is considered satisfactory for the photoinjector laser.

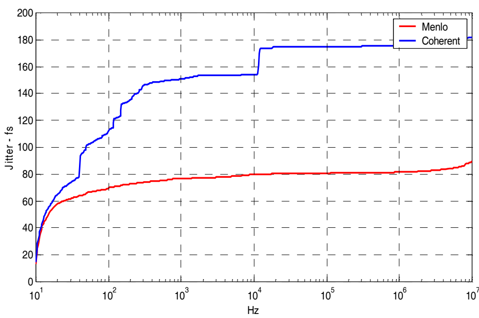

Figure 6. Timing jitter of the Ti:sapphire oscillator (blue) and an Er-doped fibre laser (red)

A question which arises naturally and to our knowledge has not been so far addressed in literature is how much jitter is added by the amplifier system. To clarify this point we pe4rformed a measurement of this jitter by monitoring the cross-correlation signal generated in a thin nonlinear crystal (BBO) by samples of the pulses before and after the amplifier. After measuring the cross-correlation (about 150 fs long nearly Gaussian), the delay was fixed at half-maximum level, so as to have maximum range where the measured fluctuation of the cross-correlation signal was linearly proportional to the timing jitter. A calibration was performed by measuring the signal change by controlled delays. The signal was measured at the rep rate of the amplifier (50 Hz). A typical 10 min record is shown on Figure 7. The jitter value extracted from this measurement was 9.8 fs. At longer time scale, the cross-correlation signal was exhibiting slow drifts, which indicates the need of implementing a beam-path stabilization of the beam-transport when the system will be installed at the photoinjector.

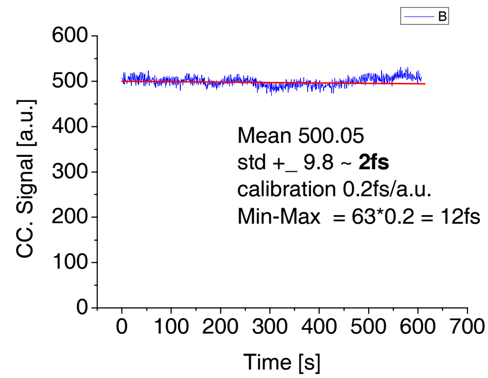

Figure 7. Typical cross-correlation signal by the jitter-measurement

CONCLUSIONS

This paper presents details on the exact setup and performance of the laser system developed for the FERMI photoinjector. The obtained results show that the implemented solutions for amplification, harmonic generation and shaping schemes were correct and allow to guarantee all the required parameters. In particular, we demonstrate for the first time the generation of the prescribed for FERMI increasing ramp UV pulse shape. We also present a first measurement of the timing jitter added by a high energy Ti:sapphire amplifier.

REFERENCES

[1] C. Limborg-Deprey, Proc.27th FEL Conf.(2005), 418.
[2] O.J. Luiten, M.J. Van der Wiel, 27th FEL Conf.(2005) ,paper WEOB003.
[3] G.Penco et al, Proc.FEL 2006, Berlin, Germany, p.625.
[4] M.B.Danailov et al, Proc.FEL 2006, Berlin, Germany, p.617.
[5] P. Tournois, Opt. Comm. 140 (1997), p.245.