DESIGN AND FIRST EXPERIENCE WITH THE FERMI SEED LASER

M. B. Danailov, A. Demidovich, R. Ivanov, I. Nikolov, P. Sigalotti, P.Cinquegrana*,
Sincrotrone-Trieste, Basovizza, Trieste

Abstract

Fermi@Elettra is the first fully seeding-based FEL. Laser operation was first demonstrated in December 2010 and later consistently studied during the runs in 2011. As it is known the seeded operation puts heavy demands on the seed laser performance. This paper describes the design of the FERMI seed laser system, including the main laser as well as the most important sub-systems and the issues that were solved to easily reach seeded operation.

INTRODUCTION

Use of seeding has been proposed in order to improve the longitudinal coherence and shot-to-shot reproducibility of the FEL pulses and is one of the basic features of the Fermi@Elettra FEL. The main requirements to the seed were set by the use of High Gain Harmonic Generation (HGHG) FEL scheme, details can be found in the FERMI CDR [1]. Here we only mention that the seed needs to be broadly tunable in UV (down to 200 nm) with a peak power above 100 MW all over the tunability range. Obviously, such a broad tunability imposed the use of a parametric amplifier, which , on the other hand, imposes some restrictions on the obtainable UV pulse energy and on the quality of the UV beam. Therefore, for the first seeding comissioning, a fixed wavelength scheme was used, allowing much higher peak power. Here we present both solutions, showing the obtained performance and the limitations. The synchronization of the laser to the timing signals was of crucial importance for the successful seeded operation so the last part of the paper briefly describes the laser synchronization setup developed for FERMI.

SEED LASER SYSTEM

The basics of the HGHG technique and how it is implemented on FERMI FEL can be found elsewhere [2,3]. Here we will only concentrate on the seed laser related aspects of seeding. As a starting point, an extensive computer simulation campaign has been performed for the Fermi HGHG scheme, with results indicating that seed laser peek power on the order of 100 MW would be needed in the 200-300 nm wavelength range in order to obtain strong enough bunching. The seed pulse duration assumed was in the 100-200 fs range, leading therefore to the need to have about 10-20 µJ of UV pulse energy reaching the modulator (first undulator). The main parameters requested to the seed pulses are summarised in Table 1 below. In the broadly tunable version (left column), which should become the standard mode of operation after completion of commissioning, the only feasible solution was obviously an optical parametric amplifier (OPA) based scheme. The OPA (a Light Conversion TOPAS C adapted to a Coherent Opera housing and controls) is pumped by a 3.3 mJ femtosecond regenerative amplifier (Coherent Elite) , which was later on upgraded by us to reach 6.5 mJ by adding one single pass amplifier stage. The signal and idler waves of the TOPAS span from 1.08 µm to about 2.6 µm, and then through a sequence of nonlinear harmonic generation and mixing

Table 1: Seed Laser Specifications

Parameter	Tunable UV	Fixed UV
Tunability range (nm)	210-280 (230-260)	261, 197 (261)
Peak power (MW)	100	>400
Pulse duration (fs)	100 (180)	<150 (150-500)
Pulse Energy Stability RMS 5000 shots	<4%	<2%
Timing jitter (fs RMS)	<50 (100)	<50 (100)
Spot in modulator (mm, 1/e2)	1	1-1.2
Wavelength stability	10-4	<10-4
Beam quality (M2)	<2	<1.5

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the frequency is up-converted to UV, the part of the spectrum than can be used for seeding the FEL is shown on Fig.1. The regions marked by orange dots have been developed and tested in the Laser laboratory of Elettra however not yet installed at FERMI. It is worth noting that these energies are measured at the OPA exit, the efficiency of the beam transport from the laser table to the undulator is wavelength dependant with values from 25% to about 50% in the range 210-280 nm.

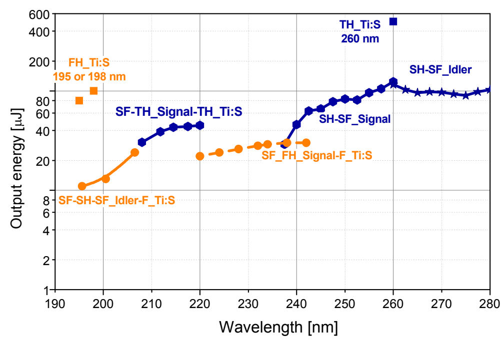

Figure 1: Tuning curve of the FERMI seed laser (at the PA exit).

While we have been able to obtain tunable light down to 195 nm (and in principle one could reach as short as 170 nm using KBBF crystal [4]), the very long and including many reflections beam transport at present limits the range to 210 nm due to high loss at shorter wavelengths. A study of the optimum compromise of seed wavelength versus harmonic order is still in progress. In addition to the tunable wavelength option, it was decided to have also a fixed wavelength beam at 260 nm (third harmonic generation, THG, of the pump laser) . This option has the advantage of providing much higher power (exceeding 500 MW) in a beam with better spatial quality and pulse-to-pulse stability (see parameters reported in the right column of Table 1). This scheme has been extremely useful for the first seeding comissioning and optimization, and may also turn out to be a valuable option in the future when a fixed wavelength higher quality FEL pulses are needed. Due to the much higher affordable losses , this option allows also to implement and study more exotic regimes like seeding with strongly chirped or differently shaped pulses. A general optical layout of the seed laser optical table, which is situated in a room above the FEL undulator hall, is shown on Fig.2. We note that a system of flippers, not fully shown on the figure, allows for an easy switching between the tunable and fixed wavelength option. In reality, the latter also allows a tunability of about 1% around the central wavelength. As it can be seen from Fig.2, the beam from the Ti:Sapphire oscillator (Micra, Coherent) which works at 78.9 MHz (half the repetition rate of the Optical Master Oscilator of the facility) is devided in three. The main part (about 50%) is used for seeding the regenerative amplifier, while the rest is divided between the locking system, briefly discussed later in the paper, and an optical crosscorrelator (XCorr) used to measure the UV pulses.

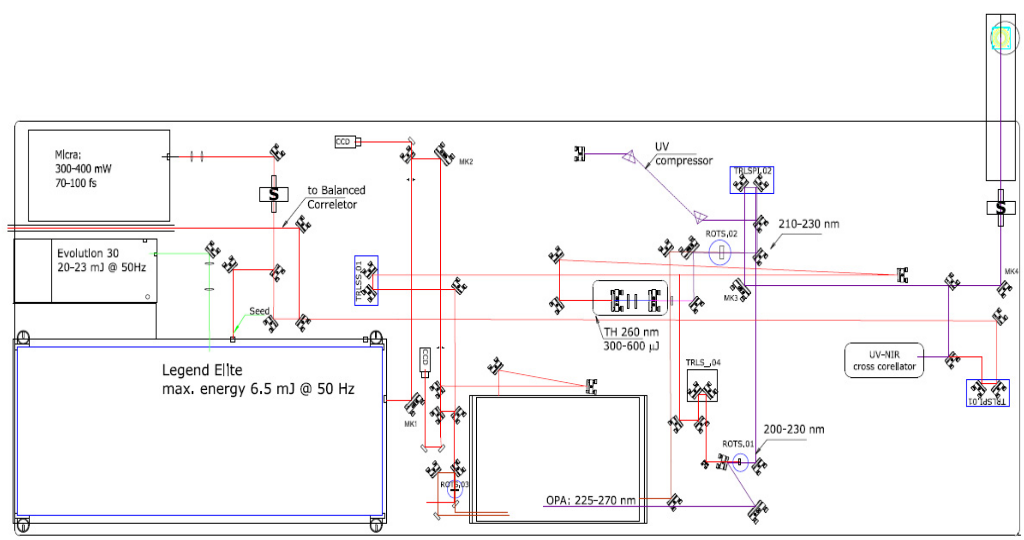

Figure 2: Layout of the main laser system.

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A typical XCorr trace of the UV pulse (THG option) is shown in Fig,3. Given that the reference pulse duration is about 80 fs, a trace of 170 fs like the one below corresponds to a UV pulse duration of about 150 fs (FWHM). Note that we have inserted in the path of the measured pulses about 15 mm of fused silica to take into account the material through which the seed beam propagates to reach the undulator, thus measuring the effective pulse interacting with the e-bunch. Without compressor it is slightly positively chirped and lengthened to about 200 fs. By adding a negative dispersion (prism compressor, as shown on Figure 2, or grating compressor as in the case of the shown trace) they can be compressed down to 150 fs or strongly negatively chirped. The typical spectral width of the UV pulses is in the range (0.7-0.9 nm), an example for the fixed wavelength case is shown on Fig.4.

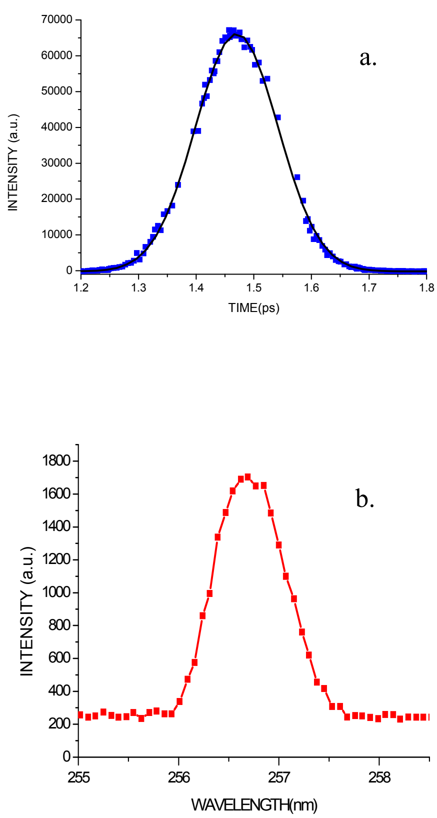

Figure 3: a. Typical XCorr trace of UV pulse at 260 nm (dots: experimental points, solid line: gaussian fit 170 fs FWHM) ;b. Typical UV pulse spectrum of the OPA option.

BEAM TRANSPORT AND INSERTION

The distance between the laser table and the point of insertion into the FEL chamber is more than 10 m, so to avoid problems due to air absorption, turbulence and nonlinearity a low vacuum beam transport has bee used for the main part of it (about 6 m). The seed beam then reaches a breadboard where beam diagnostics and steering controls are placed. A drawing of the layout of breadboard for FEL 1 is shown on Fig.4. Due to the fact that there are more then 11 m from the vacuum window to the focal region in the middle of the undulator , on the insertion breadboard a small fraction of the beam is made to propagate at such a distance using multiple reflections so as to form a 'virtual undulator' image equal to the real one. An upgrade which is planned for the near future will allow to see on the same CCD also the beam at positions about 1.5 m below and after the focus in order to be able to monitor the beam quality all over the undulator.

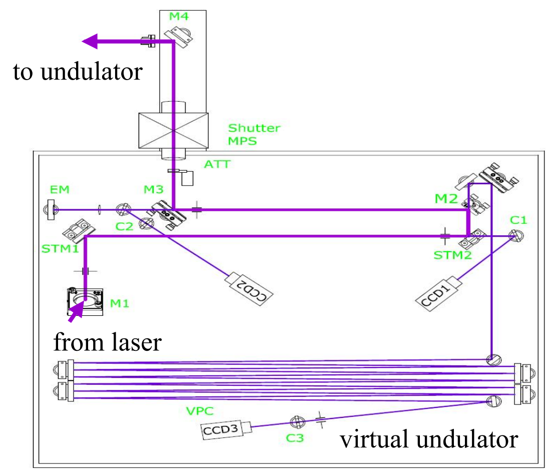

Figure 4: Insertion breadboard.

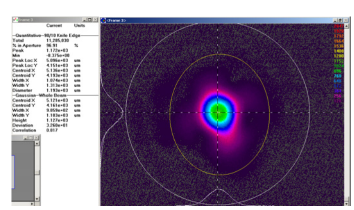

Figure 5: Typical UV beam image in the virtual undulator plane (seen by CCD3 on Fig.4).

SEED LASER LOCKING SCHEME

An extremely important point for the seed laser is also to provide the laser pulses with as small as possible timing jitter and drift with respect to the master clock of the facility (and therefore to the electron bunch). For this reason, a special attention has been dedicated to obtain a stable and low jitter locking of the Ti:Sapphire oscillator. This oscillator comes with the hardware allowing the locking already installed (intracavity Piezo, galvo and stepper motors). The commercially available electronics

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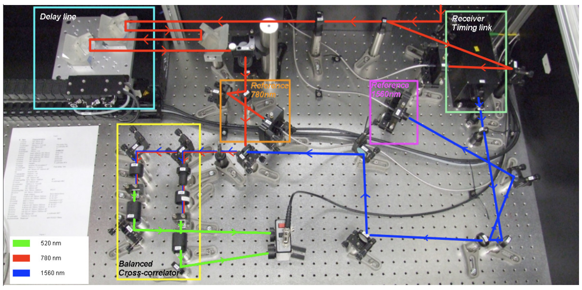
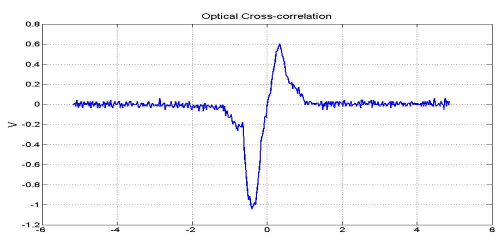
box (Syncrolock, Coherent) for locking this oscillator , is based on pure RF based error detection. This approach has well know limitations which have been overcome by the developed at Elettra laser laboratory locking scheme, based on a balanced optical Xcorr (BOCC) approach.



a.



b.

Figure 6: Photo (a) of the balanced optical Xcorr and a Xcorr trace (b).

Our system will be described in details elsewhere, here we only show a photo of the optical Xcorr (see Fig.5a) and a typical Xcorr trace. The performance of the optical locking is illustrated on Fig.7 , as it can be seen the RMS jitter is about 50 fs. The system is rather new and still under comissioning, work on improving its robustness are in progress. During the last FERMI run, it was found that having maximum uptime was better to use an RF locking , where the BOCC signal was used for monitoring and compensating the long term drifts.

Clearly, there is also a slow timing drift coming from sources after the Ti:Sapphirte oscillator (e.g. related to temperature changes of the building), whose compensation would also be nice to implement in the future. Solutions based again on optical crosscorrelation are under study. At present, such drifts are compensated by optimising the strength of the FEL signal by scanning of the delay line inserted on the 780 nm pulses before their entrance into the BOCC (marked by a square in the upper left corner of Fig.6a.

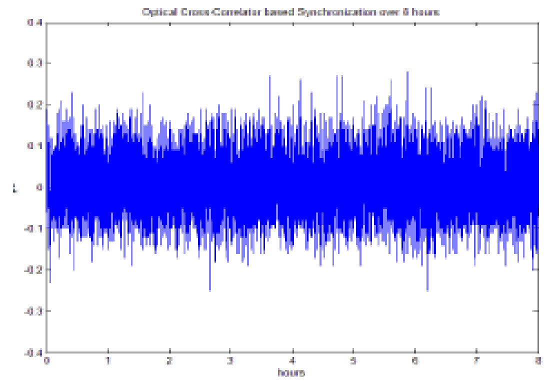


Figure 7: Long term measurement of the BOCC based locking , RMS=53 fs.

CONCLUSIONS

The operation of the FERMI FEL has started only recently, demonstrating the feasibility of fully seeded operation and the importance of the performance of the seed laser. The first results are promising and indicate potential for further improvement of the FEL parameters for the users, as well as for exploring new aspects of FEL physics [3].

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