FEL COMMISSIONING OF THE FIRST STAGE OF FERMI@ELETTRA

G. De Ninno#, E. Allaria, M. Cornacchia, S. Di Mitri, B. Diviacco, G. Penco, C. Spezzani, M. Trovò, Sincrotrone Trieste, Trieste, Italy.

Abstract

The commissioning of the first stage of FERMI@Elettra (FEL-1) has started on 6 July 2009. During the first year of operation, the effort will concentrate on the optimization of the gun performance, as well as of the electron-beam acceleration and transport through the LINAC. By fall 2010, it is our aim to generate out of the LINAC an electron beam as similar as possible to the one needed for achieving the nominal (i.e., user-required) FEL performance. Such a beam will be injected into the undulator chain and used to get the first FEL light. In this paper, we present our strategy for the commissioning of the FEL process, both in SASE and seeded configurations. On the basis of start-to-end simulations, we also discuss the expected FEL performance for day-one operation.

STRATEGY FOR FEL COMMISSIONING

FEL-1 will rely on a seeded harmonic generation scheme [1], see Figure 1.

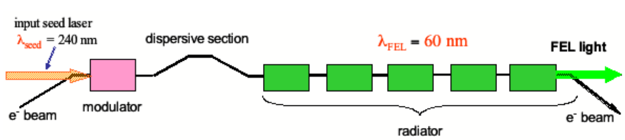

Figure 1: Schematic layout of FEL-1. For the complete list of working parameters, see [2].

For the commissioning, we foresee the following phases.

Electron-Beam Alignment

During this phase, use will be made of the Beam-Based Alignment (BBA) technique to transport the electron beam through the vacuum chamber and define a reference trajectory. In order to avoid damaging the poles trough beam loss, the undulators will be installed after the successful implementation of BBA. A refined BBA will be then repeated after the undulators' installation, closing the undulator sections at a time.

Obtain and Optimize SASE Radiation at 60 nm

After the electron-beam alignment, the electron-beam energy, energy spread, charge, duration, energy profile and stability will be measured at the end of the linac. The radiator will be tuned at 60 nm (the modulator will stay open): the sections will be closed one by one and the spectrum of the emitted (spontaneous) radiation will be measured at the end of the undulator chain. After that, in order to tune the phase shifters placed in each intra-section, the spectrum of the radiation emitted by two consecutive sections will be measured and optimized as a function of the phase shift induce by the intra-section phase shifters. Finally, all sections will be closed in order to generate (saturated) SASE radiation at 60 nm. Such a radiation will be characterized in terms of power, spectrum, polarization, temporal and spatial coherence.

Generation and Optimization of Harmonic Generation at 60 nm

As a preliminary condition for obtaining a seeded signal, a good spatial and temporal overlap must be insured between the seed laser and the electron beam. This will guarantee the creation of the required electron-beam energy modulation inside the modulator. As for the spatial overlap, two fluorescence screens, one placed before the modulator and one at its exit, will be used to check and optimize the superposition between the laser and the electron beam. A good synchronization system (providing a jitter in the arrival time of the seed laser with respect to the electron beam below 150 fs rms) should be available already from the first day of commissioning [3].

At the exit of the modulator, the energy-modulated electron beam passes through the dispersion section, where the bunching is created. The diagnostics placed at the end of the dispersive section will be used to measure and optimize the fundamental and harmonic bunching before the injection of the beam into the radiator. The radiator will be initially tuned at 60 nm (fourth harmonic of the seed laser). The optimization of dispersive section strength and of the phase shifters should allow to reach saturation. The saturated FEL pulse will be characterized at the exit of the radiator: power, spectrum and (possibly) duration will be measured. The same procedure will be then repeated at shorter wavelengths (i.e., higher order harmonics of the seed laser), for different undulator polarizations.

EXPECTED PERFORMANCE FOR DAY-ONE OPERATION

Electron-Beam Characteristics for Day-one Operation

According to the present schedule [4], FEL-1 will be commissioned in the absence of the laser heater and of the X-band cavity. As a consequence, the initial electron-beam quality is expected to be significantly worse than that which will be obtained with all components in place, and which is necessary in order to reach the nominal (user-required) FEL performance [5]. In spite of that, the start-to-end simulations reported in the following, and

#Also University of Nova Gorica, Slovenia performed using the numerical codes LiTrack [6], elegant [7] and Genesis [8], support the possibility of accomplishing the commissioning goals outlined in the previous Section.

The following plots show the electron-beam energy, current, emittance and energy-spread profiles, as obtained using the codes LiTrack and Elegant. The beam has a duration of about 1 ps and is strongly non-uniform, both in energy and in current, see Figs.2 and 3. In particular, the energy profile displays a steep nonlinear chirp, which is eventually likely to result both in a shift of the FEL wavelength and in a broadening of its bandwidth. The head of the bunch is characterized by a current spike, which cannot be smoothened due to the absence of the X-band cavity.

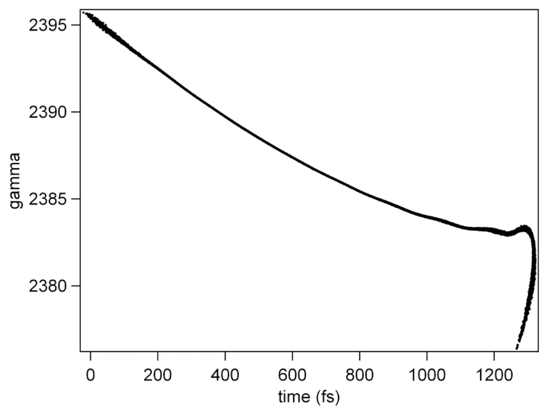

Figure 2: Electron-beam energy profile.

On the other hand, the emittance is instead quite uniform along the bunch (see Figure 4) and has a value in the range 0.6-0.8 mm mrad, which is a factor about 2 smaller than that required for the nominal FEL-1 operation. The value of energy spread (see Figure 5) is about two times larger than the nominal one (150 keV) at half-height of the current spike (about 300 keV), and significantly less than the nominal one in the central part of the bunch (<100 keV).

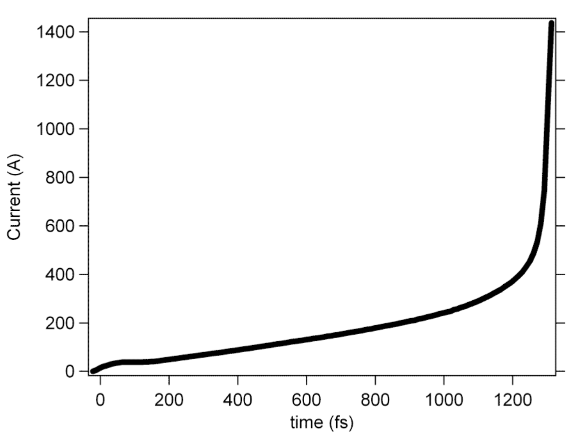

Figure 3: Electron-beam current profile.

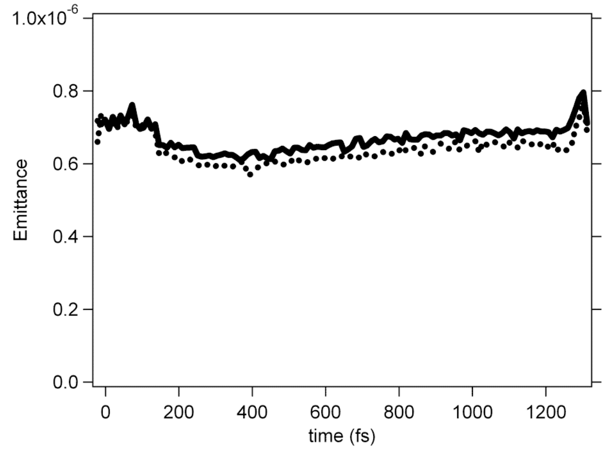

Figure 4: Electron-beam horizontal (full line) and vertical (dotted line) emittance profiles.

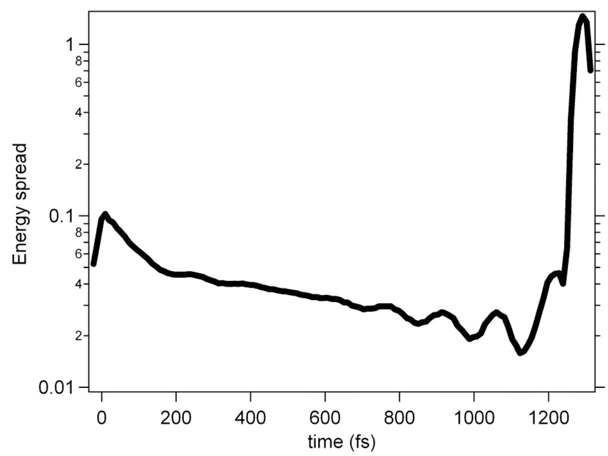

Figure 5: Electron-beam energy spread profile.

SASE Simulation

A time-independent SASE simulation at 60 nm has been performed in order to tune the resonance condition and optimize the FEL process. As the SASE is likely to grow in correspondence of the current spike, the beam parameters in that region have been used as a reference for the simulation. Figure 6 shows the growth of the FEL power as a function of the undulator distance. The power saturates after six undulator sections (about 17 m) and the output peak power is of the order of few GW.

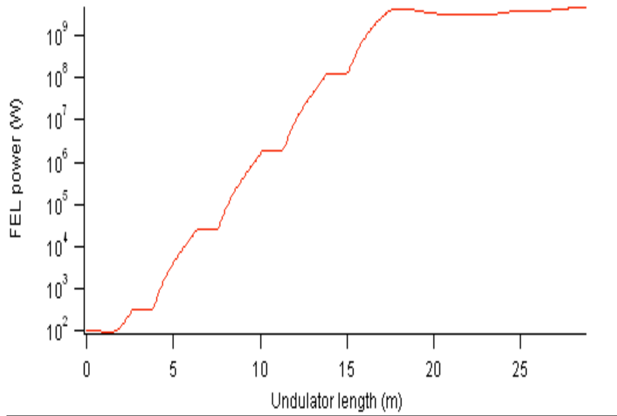

Figure 6: SASE power at 60 nm as a function of the undulator distance. For the simulation, we used the beam parameters corresponding to half-height of the current spike shown in Figure 3, that is: energy: 1.22 GeV, energy spread: 300 keV, current: 900 A, emittance: 0.7 mm mrad.

Figures 7 and 8 show, respectively, the temporal profile and the spectrum of the output SASE pulse, as a result of a start-to-end time-dependent simulation in which the beam distribution generated by elegant (see previous Section) has been used as an input for Genesis. As expected, the FEL power is maximum in correspondence of the spike. The spectrum looks relatively clean. The expected performance in terms of peak power and number of photons in a given band is reported in Table 1.

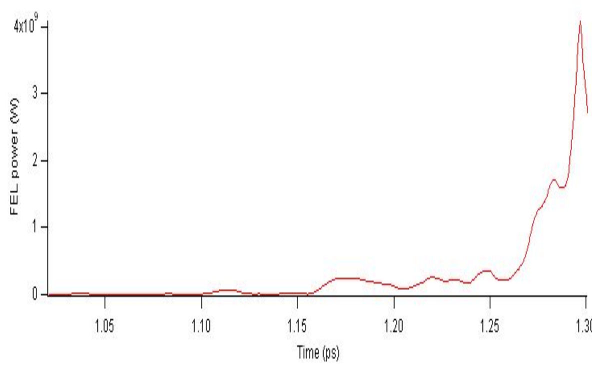

Figure 7: SASE pulse profile at 60 nm.

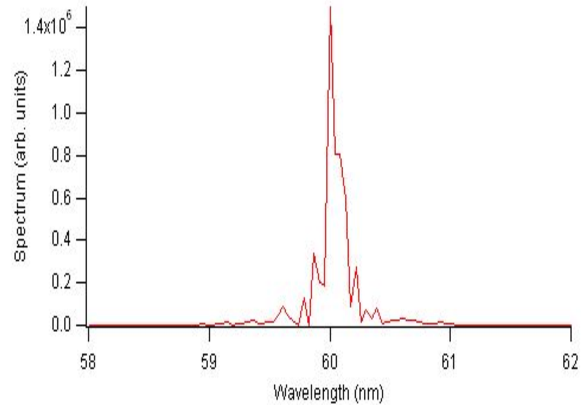

Figure 8: SASE spectrum at 60 nm.

HGHG Simulations

Although far from the nominal one, the day-one setup will also allow us to test the generation of FEL radiation in seeded operation mode. We report here the results of simulations at 60 nm (fourth harmonic of the seed laser). Figure 9 shows the time-independent optimization of the power growth inside the radiator. As expected, compared to the SASE case, the saturation occurs within a shorter undulator distance (four radiator sections, i.e. about 14 m, instead of six). The parameters used for the simulations correspond to the center of the electron bunch (see figs. 2-5), characterized by a smaller peak current but also a smaller energy spread.

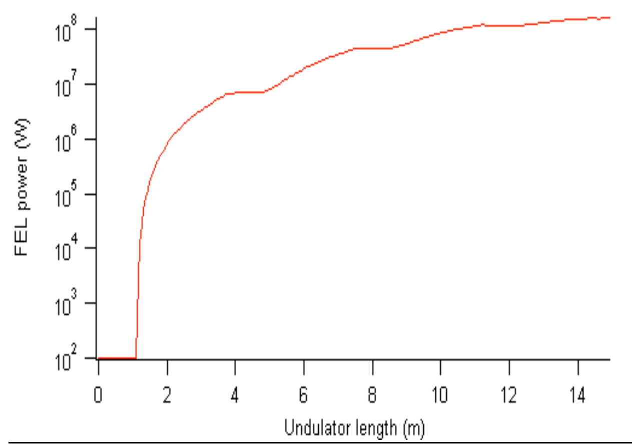

Figure 9: HGHG power at 60 nm as a function of the radiator length. For the simulation, we used the parameters corresponding to the center of the electron bunch (see figs. 2-5), i.e.: energy: 1.22 GeV, energy spread: 20 keV, current: 200 A, emittance: 0.7 mm mrad.

Figures 10 and 11 show, respectively, the temporal profile and the spectrum of the output FEL pulse, as a result of a start-to-end time-dependent simulation. The seed pulse is 100-fs (FWHM) long and is "synchronized" in the modulator with the central part of the electron bunch. Looking at Figure 10, one can see that reducing the radiator length to four sections allows to avoid the SASE "contamination" due to the current spike (which is becoming stronger and stronger as the radiator length is increased). The expected performance in terms of peak power and number of photons in a given band is reported in Table 1.

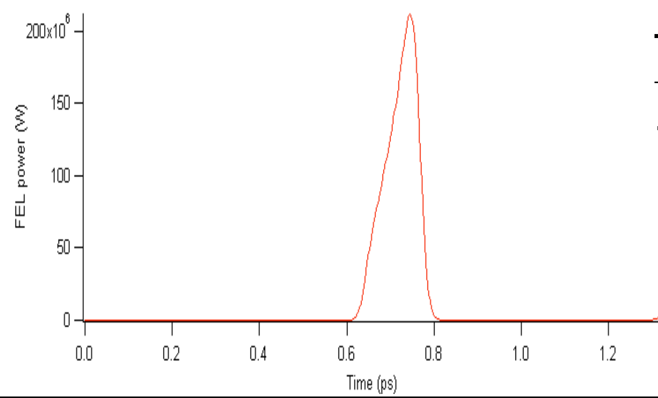

Figure 10: HGHG pulse at 60 nm.

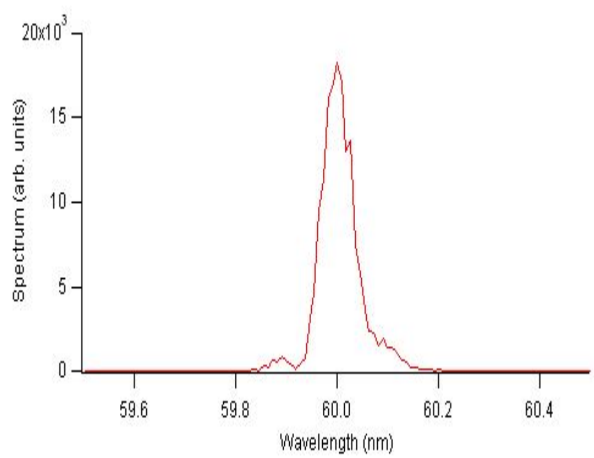

Figure 11: HGHG spectrum at 60 nm.

The following Table shows the FEL-1 day-one expected performance.

Table 1: Expected performance of SASE and HGHG for day-one FEL-1 operation.

	Pulse duration (FWHM)	Photons number	Bandwidth containing 90% of photons	Photons in $3{\cdot}10^{-4}$ bandwidth
SASE	~ 20 fs	$2{\cdot}10^{12}$	$1.4{\cdot}10^{-2}$	$1.2{\cdot}10^{11}$
HGHG	~ 90 fs	$6{\cdot}10^{10}$	$2.4{\cdot}10^{-3}$	$1.4{\cdot}10^{10}$

REFERENCES

[1] See, e.g., L. H. Yu, Phys. Rev. A 44, 51178 (1991).
[2] http://www.elettra.trieste.it/FERMI/.
[3] M. Ferianis, Private communication.
[4] S. Di Mitri et al., Presentation to MAC, June 2009.
[5] F. Parmigiani, Private communication.
[6] K. Bane, P. Emma, PAC'05, FPAT091, Knoxville, Tennessee, USA.
[7] M. Borland, APS LS-287 (2000).
[8] S. Reiche, Nucl. Instr. and Meth. 429 (1999) 243.

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