REQUIREMENTS FOR FEL COMMISSIONING AT FERMI*

E. Allaria, G. Penco, C. Spezzani, Sincrotrone Trieste SCpA, Trieste, Italy.
G. De Ninno#, University of Nova Gorica, Slovenia; Sincrotrone Trieste SCpA, Trieste, Italy.

Abstract

The commissioning of the first stage (FEL-1) of FERMI@Elettra [1] has started in the summer 2009. During the first year of operation, the efforts will mainly concentrate on the optimization of the gun performance, as well as on electron-beam acceleration and transport through the LINAC. By fall 2010, it is planned to generate out of the LINAC an electron beam that will be injected into the FEL-1 undulator chain and used to obtain the first FEL light. In this paper, we present the requirements for FEL-1 commissioning, both in terms of hardware and electron beam properties.

STRATEGIES FOR FEL COMMISSIONING

This paper describes the requirements for starting the operation of the FERMI FEL in order to produce the first FEL light. The latter will be used to achieve the partial commissioning of the FERMI beamlines, and to perform the first users experiment. Of course, since it won't be possible to consider at this stage the machine installation completed, the properties of the first FEL radiation will be not coinciding with the nominal performances. [1]. In particular, for this first period we envisage a fixed wavelength operation of the FEL at about 60 nm. The goal is to provide FEL pulses with few tens of µJ with a pulse length of about 100fs. Moreover, we can expect large power fluctuations from shot to shot as well as a relatively large bandwidth.

Up to now, the SASE operation of the FEL has been considered as the simplest way to start the FEL commissioning [2]. However, things may be different if the electron-beam parameters and/or the available hardware will not allow reaching in an easy way the FEL saturation. In that case, we believe that a configuration relying on Coherent Harmonic Generation (CHG) will be the most indicated to produce a suitable FEL pulse in the 50-60nm spectral range.

In the following, we will present the two possible approaches, SASE and CHG, and review the advantages and disadvantages of both configurations.

SASE FEL

The operation of a SASE FEL "just" requires a stable and aligned electron beam passing through a well-aligned radiator. With respect to a seeded FEL, the big advantage of the SASE scheme is that it does not require any external laser or source to initialize the process. Neither the seed laser, nor the timing jitter are an issue for such a configuration.

However, the operation of a SASE FEL may become critical if the radiator is not long enough to allow reaching saturation with the available electron beam parameters. In fact, SASE FEL is initialized by the spontaneous emission (shot noise) of the electron beam entering into the radiator and typically about 20 undulator gain lengths are needed before the FEL reaches saturation. Starting from noise, after a "lethargic length", the FEL grows exponentially along the radiator. It is therefore clear that the process is quite sensitive to the available radiator length, and also to the electron beam parameters (i.e., current, emittance, energy spread) strongly affecting the gain-length.

The first period of FERMI operation will rely on a limited number of radiator sections [3]: six instead of eight (as initially required). This imposes strong requirements to the electron-beam parameters allowing to reach saturation in SASE mode.

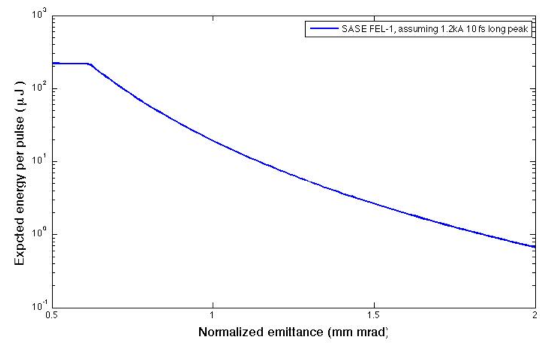

Figure 1: Expected energy per pulse as a function of emittance, in SASE configuration. The calculation relies on M. Xie's formula [8]. It is performed using six undulator sections and assuming a peak current of 1.5kA.

According to our calculations, in order to reach saturation at 60nm using six undulator radiator sections, an electron-beam is required having a peak current of about 1.8kA, an emittance of 0.8 mm mrad and an energy spread of about 400keV. Such electron-beam parameters may not be available during the first period of commissioning of the FERMI LINAC. Indeed, the goals that have been fixed for the first commissioning period of the FERMI LINAC are [4]: a peak current of the order of 500A, a normalized slice emittance in the range 1.5-2.5 mm-mrad, and an uncorrelated slice energy spread of 400 keV. The possibility to reach saturation using such a beam is limited to the use of eight undulators, and only in circular polarization.

An intrinsic disadvantage of the SASE configuration is that in the case it is not possible to reach or at least approach saturation, the extracted power may be very weak. In particular, for the expected electron-beam parameters, and with only six undulators, only few tens of MW will be extracted in circular polarization, and even less in horizontal polarization.

In order to extract at least 0.5 GW at 60 nm at the exit of the sixth undulator the electron beam should be characterized by a current of 1500 A and by an emittance of 1.5 mm mrad.

CHG FEL

Similarly to the SASE FEL, the CHG configuration has stringent requirements in terms of alignment of the electron beam and undulators, that may be achieved with the use of a Beam Based Alignment (BBA) procedure.

However, the CHG is generally less demanding in terms of electron beam properties. The first period of operation of the LINAC and of the FEL will be based on a non-ideal electron beam, with relatively strong nonlinearities in the longitudinal phase space. Although these nonlinearities will strongly affect the properties of the FEL pulse, they will not prevent to implement a CHG seeded FEL, especially at relatively long wavelengths (50-60nm).

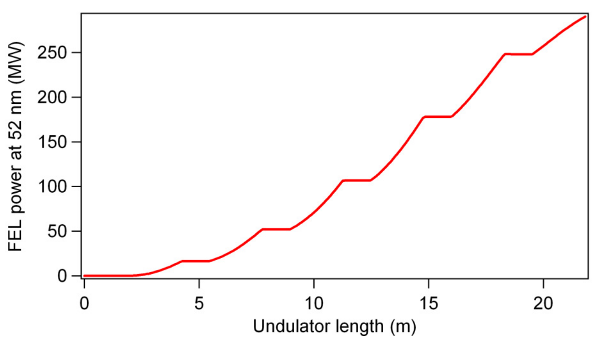

Figure 2: Predicted FEL power evolution at 52nm in the final radiator, in CHG configuration. The simulation is done with GINGER making use of an electron beam with an emittance of 1.5 mm mrad, energy spread 400 keV and peak current of 200 A.

An advantage of the CHG is that the FEL process does not rely on shot noise. Due to the seeding process occurring in the modulator, electrons emit coherently at one of the seed harmonic wavelengths when entering the radiator. Such a coherent emission is several orders of magnitude stronger than spontaneous emission, and allows reaching saturation in a few gain lengths. Another important advantage of CHG with respect to SASE is that the coherent emission of the bunched electron beam within a single undulator could be strong enough (>10MW) to be used for starting the commissioning of the beamlines. This makes the implementation of CHG less sensitive to the available number of undulators with respect to the SASE.

On the other hand, the main "disadvantage" of CHG is that it requires a seed. This means that a seed laser well aligned with the electron beam within the modulator should be available and that the jitter between the seed pulse and the electron pulse should be at least comparable with the bunch duration (about 1 ps).

According to numerical simulations, about 0.5GW at 65nm could be achieved using six radiator sections by seeding the electrons at 260 nm, also with an electron beam with 400A of peak current, 400keV of energy spread and 2.5 mm mrad of normalized emittance.

REQUIREMENTS FOR FEL COMMISSIONING

Before starting the FEL commissioning the electron beam with the required characteristics has to be well aligned within the radiator line. It is then required that the BBA will be implemented. This in turn requires that the Cavity BPMs should be installed and in operation.

The electron beam should be well matched all along the radiator chain. This requires the intra radiator multi screens (IRS) to be installed and operational.

A machine protection system for monitoring the radiation dose on the undulators should be installed and operational.

Diagnostics to detect photon-beam position (and intensity) should be operational in the intra-radiator sections, and at the FEL end.

In general, a stable and reproducible electron beam should be available. In particular, it is required to have a reliable measurement of e-beam:

- energy, mean and slice;
- energy spread, projected and slice;
- emittance, projected and slice;
- current, slice;
- pulse length;
- timing jitter.

The accuracy of measurement of the electron-beam energy is required to be better than 1%. For all other measurements, we require an accuracy of 10%.

For some of these measurements, it is required that the high energy deflecting cavity will be already installed and in operation.

Requirements specific for SASE

For SASE, it is required that at least six radiator undulators will be installed, together with the corresponding intra-radiator diagnostics and components.

Most probably, SASE operation will start with circularly polarized undulators. If needed, alignment of the circularly polarized undulator should be performed with BBA.

Electron-beam parameter should allow FEL saturation within the available radiator length (see previous Sections).

Requirements specific for CHG

A successful implementation of CHG requires the installation of the modulator [5], the dispersive section [6] and the seed laser [7].

For the commissioning, use will be made of a seed at fixed wavelength, characterized by pulse energy higher than nominal, and by relatively long pulses. In particular, a laser delivering more than 100MW at 260nm with a pulse of about 1ps is recommended.

The screens before and after the modulator should be operational and allow monitoring the spatial superposition between the seed laser and the electron beam. An Electro-Optical Sampling station should allow detecting the arrival time of the seed laser and of the electron beam, in order to measure the temporal superposition of the two pulses.

It is required that the diagnostics after the modulator will be installed and operational, allowing to measure the micro-bunching structure created in the electron beam by the seeding process.

In order to produce more than 100MW of FEL radiation, more than three radiator undulators should be installed and operational.

To meet the goals of the first period of commissioning the electron beam parameter for CHG are relatively more relaxed than for SASE. An optimal starting point would be:

Peak current	> 500A;
Energy spread	< 400keV;
Emittance	< 2.0 mm mrad.

For CHG operation, the control and minimization of the electron-beam timing jitter is critical. The same holds for the minimization of electron-beam energy fluctuations. A timing jitter lower than 1 ps and energy fluctuation lower than 0.5% are required.

PLAN FOR FEL COMMISSIONING

The first part of the commissioning will be dedicated to insure a perfect alignment of all hardware components with the electron beam. For that, use will be made of BBA. In order to avoid any risk of damaging, undulators will be installed after the successful implementation of BBA. A refined BBA will be then repeated after undulators' installation, closing the undulator section by section.

The electron beam entering the undulators will be characterized by measuring both projected and slice electron beam parameters.

The spontaneous emission generated by the electron beam passing through single undulators will be used to commission the photon-beam diagnostics, both intra-undulator and downstream the radiator.

Then, the radiator sections will be tuned at 60 nm (the modulator will stay open): 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.

The measurements of the spectral properties will be used for the calibration of undulators and for obtaining their fine alignment.

Plan specific for SASE

After the calibration of each undulator, 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 reciprocal phase shift. Finally, all sections will be closed in order to generate SASE radiation at about 60 nm.

Plan specific for CHG

As a preliminary condition, 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. A good synchronization system (providing a jitter below 1 ps) should be available already from the first day of commissioning.

The diagnostics placed at the end of the dispersive section will be used to measure and optimize the (fundamental and harmonic) bunching before injection of the beam into the radiator.

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