FEL PERFORMANCES OF THE FRENCH LUNEX5 PROJECT

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Abstract

LUNEX5 is a French FEL test facility project based on two types of accelerators: a Conventional Linear Accelerator (CLA) and a Laser WakeField Accelerator (LWFA) [1, 2]. The FEL performances will be presented at 20 nm, 17 nm and 12 nm, wavelengths of interest for the pilot experiments. Results are obtained with GENESIS simulations in time-dependent mode [3]. At 400 MeV, the nominal energy, we compare different seeded schemes as EEHG scheme (Echo Enabled Harmonic Generation) [4] or HGHG scheme (High Gain Harmonic Generation) [5] using HHG source (High Harmonic Generation in Gas) [6, 7]. At 220 MeV (first phase of the CLA), we test the EEHG performances at 17 nm, using 800 nm laser seeds. In parallel, LWFA FEL performances are presented as a function of the electron bunch characteristics, in particular the bunch length and the energy-spread.

PARAMETERS

Electron bunches The electron bunch parameters used in the simulations are given in the table 1 [2].

Table 1: Electron bunch parameters used in the simulations.

	CLA - 400 MeV	CLA - 220 MeV	LWFA
Energy (MeV)	400	220	400
Slice relative energy spread	2×10^{-4}	1×10^{-4}	1×10^{-3} or 5×10^{-3}
Emittance $\epsilon_{x,y}$ (π.mm.mrad)	1.5	1.2	1
Peak current (kA)	0.4	0.1	1 or 10
Charge (nC)	1	1	50×10^{-3}

Undulator and lattice The undulators are used either to modulate the electron bunch energy at the external laser seed wavelength (modulator) or for the amplification & emission (radiator). The standart 400 MeV operation with the CLA and LWFA is designed with four in vacuum U15 (planar undulator with a period of 15 mm) with 200 periods, and two U30 with 10 periods for the EEGH modulators. For CLA at 220 MeV it has been considered to use only one radiator composed of 400 periods of 12 mm (1 T peak field), and two U40 with 10 periods for the EEHG modulators (1 T peak field). To guide the electron bunch along the radiators, a FODO lattice is used (RMS width is about 100 μm in both horizontal and vertical plane [8]).

Laser seed In all cases, our FEL relies on the use of external sources for seeding. Two types of seed will be essentially used: high power long wavelengths seeds (800 nm from Ti:Sa laser and its third harmonic using non-linear crystals) and lower power but short wavelengths seeds based on harmonic generation in gas [9].

GENESIS configuration Simulations are performed with GENESIS in time-dependent mode [3]. For HGHG and EEHG scheme, simulations are performed in several steps (two for HGHG and three for EEHG), to simulate first the energy modulation(s) and then the amplification & radiation. Frequency conversion are obtained using the *convharm* option. To limit numerical noise for high harmonics (typically 50), it is necessary to use a high number of macro-particles (typically 50 000 per slices). For these simulations, chicanes are simply modeled by the R_{56} term in the transfer matrix (*itram* option).

PERFORMANCES WITH THE CLA

With the CLA, two schemes are used to obtained fully coherent pulses at short wavelength: the High-Gain Harmonic Generation scheme (HGHG) using High Harmonic Generation in gas source (HHG) and the EEHG scheme.

Radiation at 20 nm with a energy of 400 MeV and the HGHG scheme

Figure 1 presents the HGHG layout and results. The U30 modulators are kept open. Seeding is performed in the first U15 tuned at 40 nm using Harmonic Generation in Gas at 40 nm [6, 7]. The three others U15 are tuned at 20 nm. Therefore, the second harmonic of the energy modulation performed in the first section is exploited in the last sections. The main results are presented in Figure 1. The final power is about 0.27 GW, within a 17 fs FWHM pulse duration and 0.02 nm FWHM bandwidth. Saturation is reached after 4 sections: 1 for modulation and 3 for radiation.

Radiation at 20 & 12 nm, with a energy of 400 MeV and the EEHG scheme

In the EEHG configuration (see Fig. 2), the two modulators are tuned at the seed laser wavelength (266 nm). For the two wavelengths (20 and 12 nm), the first laser power is chosen to modulate the electron energy with an amplitude of about 5 energy spread (P_{L1}=15 MW) [10]. The first chicane is also fixed for all the wavelength, and is chosen to induce a $R_{56}^{(1)}$ of 2 mm. Then the second laser power P_{L2} and the second chicane are tuned to maximize the bunching factor at the desired wavelength. At 20 nm, P_{L2}=30 MW and $R_{56}^{(2)}$=0.16 mm. At the entrance of the radiator (i.e. at the exit of the second chicane), the bunching factor at 20 nm is non-null along the overlapping of the two seed laser pulses (of width 30 fs FWHM) and its maximum

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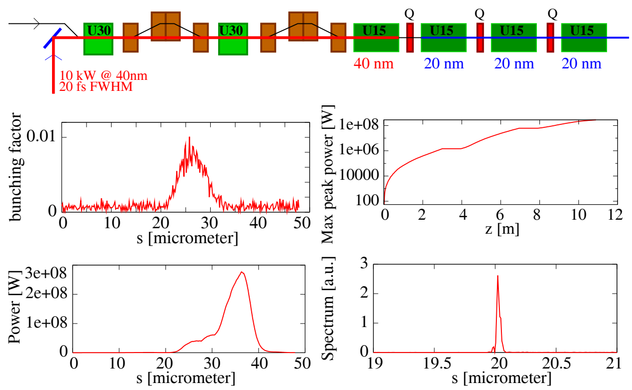

Figure 1: FEL at 20 nm in the HGHG configuration. (i) Bunching factor at the radiator entrance (ii) Power vs undulator radiator sections. Longitudinal (iii) power and (iv) spectral profile after the 4th radiator. Seed: 20 fs FWHM pulse with 10 kW peak power at 40 nm.

is of 9%. The saturation is reached within two undulator sections tuned at 20 nm, and the maximum peak power is of 70 MW, with a RMS width of about 10 fs. The saturation power is smaller with the echo scheme than with the HGHG scheme, since in the echo case, the electron bunch energy spread is increased by the laser interactions.
For radiation at 12 nm (see Fig. 3), the first laser power and the first chicane have the same characteristics that for the 20 nm case (P_{L1}=15 MW and $R_{56}^{(1)}$=2 mm). The second laser power P_{L2} and the second chicane are tuned to maximize the bunching factor at 12 nm (more precisely at 12.1 nm, the 22th harmonic of the 266 nm), P_{L2}=88 MW and $R_{56}^{(2)}$=0.08 mm. The radiator is tuned at 36.3 nm. At the entrance of the radiator (i.e. at the exit of the second chicane), the maximum bunching factor at 12 nm is about of 3%. The saturation is reached within only one undulator section tuned at 36 nm, and the maximum peak power is of 30 MW, with a RMS width of about 3 fs.

Radiation at 17 nm, with a energy of 220 MeV and the EEHG scheme

As a first phase of the CLA part, we also consider a limited energy of 220 MeV (obtained with one section of cryogenic RF cavity). FEL performances are estimated at the wavelength of 17 nm (see Fig. 4). The laser seed wavelength is 800 nm in order to test the frequency conversion at a high harmonic number (47 in this case). The first laser power is chosen to modulate the electron energy with an amplitude of about 5 energy spread (P_{L1}=5 MW), the second laser power is P_{L2}=20 MW. The first chicane is chosen to induce a $R_{56}^{(1)}$ of 12 mm, and the second chicane a $R_{56}^{(2)}$ of 0.25 mm. At the entrance of the radiator, the maximum bunching factor at 17 nm is of 5%. The saturation is reached within one undulator section tuned at 51 nm, and the maximum peak power is of 10 MW, with a RMS width of about 5 fs (95 nJ per pulse). The initial bunching factor presents a noisy aspect, which can be due to numerical

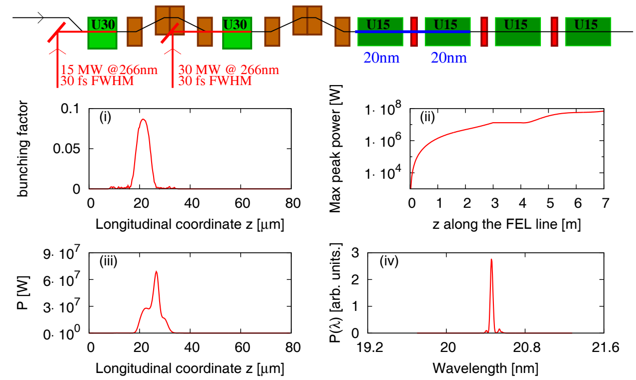

Figure 2: FEL at 20 nm in the EEHG configuration. (i) Bunching factor at the radiator entrance. (ii) Maximum peak power vs undulator radiator sections. Longitudinal (ii) power and (iv) spectral profile after 2 sections of radiators. Seed: 30 fs-FWHM pulse with 15 MW and 30 MW peak power at 266 nm.

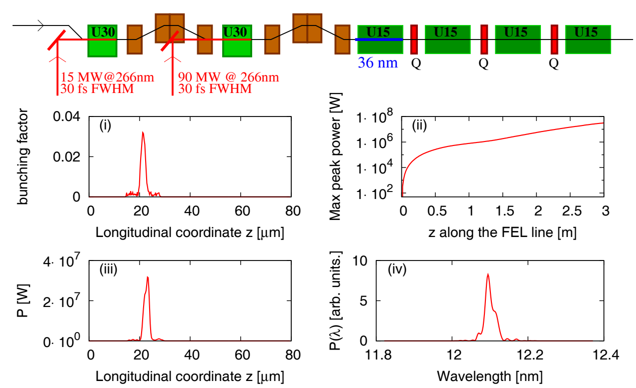

Figure 3: FEL at 12 nm in the EEHG configuration. (i) Bunching factor at the radiator entrance. (ii) Maximum peak power vs undulator radiator sections. Longitudinal (iii) power and (iv) spectral profile after 1 section of radiator. Seed: 30 fs-FWHM pulse with 15 MW and 88 MW peak power at 266 nm.

effects appearing during the frequency conversion. This noise in the bunching factor certainly modified also the radiation characteristics.

PERFORMANCES WITH THE LWFA

With the Laser-WakeField Accelerator, simulations are performed with two set of optimistic parameters. In the two cases, the electron bunch energy is of 400 MeV and the FEL is simulated in the seeded and SASE configurations, for a resonant wavelength of 20 nm.

With abunch length of 2 fs RMS [11] and 0.1% energy spread (Fig. 5), both configurations (SASE and seeded) give similar results. The FEL saturates after two radiator sections, at 2 GW. The pulse duration is about 5-7 fs-FWHM: the initial electron bunch length is not dramatically stretched inside the first two radiators. With respect to

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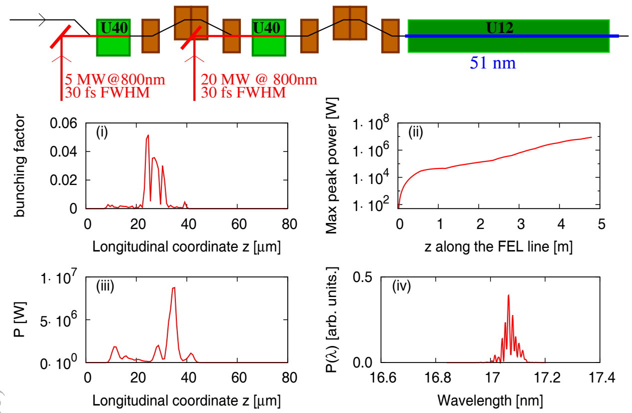

Figure 4: FEL at 17 nm in the EEHG configuration. (i) Bunching factor at the radiator entrance. (ii) Maximum peak power vs undulator radiator section. Longitudinal (iii) power and (iv) spectral profile after 1 section of radiators. Seed: 30 fs-FWHM pulse with 5 MW and 20 MW peak power at 800 nm.

the CLA based FEL, this LWFA based FEL shows a much shorter saturation length, higher output power and shorter pulse duration. The seeding might help at the beginning for FEL optimization, to get significant power within one section. But the natural bunch can intrinsically provide single spike both in time and spectral domains.

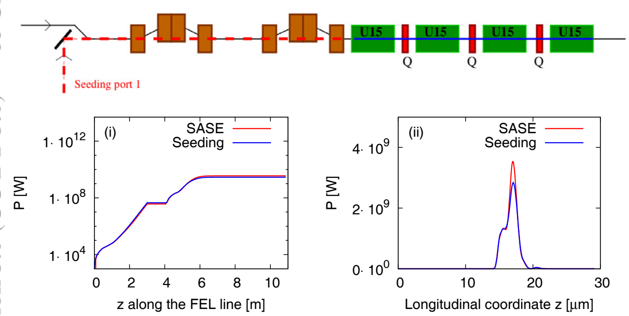

Figure 5: FEL performances at 400 MeV in SASE (red line) and Amplifier configuration (blue line)(seed power:1 kW), at 20 nm. (i) Output power along the radiator sections. (ii) Longitudinal power distribution at the exit of the second radiator. Electron bunch duration: 2 fs RMS, peak current: 10 kA, energy spread:10^{-3}.

In the case of a longer electron bunch, i.e. 20 fs RMS and a higher energy spread (0.5%) (Fig. 5), the peak current is dramatically reduced, leading to a lengthening of the saturation length. The SASE FEL does not reach saturation within the radiators, limiting its output power to a few MW. The FEL does not reach saturation within the radiators, limiting its output power to less than a MW.

CONCLUSION

We present FEL performances of the two parts of the LUNEX5 project: using electron bunches accelerated with

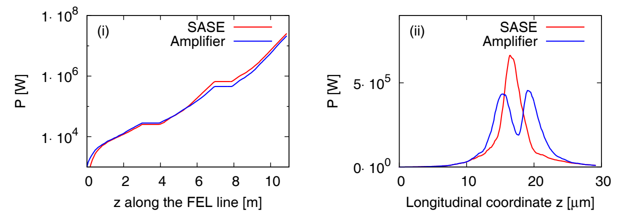

Figure 6: FEL performances at 400 MeV in SASE (red line) and Amplifier configuration (blue line)(seed power:1 kW). (i) Output power along the radiator sections. (ii) Longitudinal power distribution at the exit of the third radiator. Electron bunch duration: 20 fs RMS, peak current: 1 kA, energy spread: 5×10^{-3}.

a Conventional Linear Accelerator (until 220 MeV and 400 MeV) and using electron bunches obtained with Laser-WakeField Acceleration. Simulations are performed with the GENESIS code in the time-dependant mode.

Futur studies will focus on more detailled electron-bunch dynamics (start-to-end simulations, details of chicane) and on performance sensibilities to parameters (bunch energy, laser power, etc.).

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