SENSITIVITIES OF FEL PARAMETERS IN LUNEX5 IN FRANCE BY GENESIS SIMULATION

T. Tanikawa, M.E. Couprie, M. Labat, A. Loulergue, Synchrotron SOLEIL, Saint-Aubin, France
S. Bielawski, C. Evain, C. Szwaj, PhLAM/CERLA, Villeneuve d'Ascq, France

Abstract

LUNEX5 (free-electron Laser (FEL) Using a New accelerator for the Exploitation of X-ray radiation of 5th generation) aims at producing short and intense laser pulses in the soft x-ray region. This FEL comports either a conventional linear accelerator or a laser wakefield accelerator, and includes an innovative schemes such an echo-enable harmonic generation and a higher-order-harmonics seeding generated in gases to obtain a high spatio-temporal coherent radiation. Sensitivities of FEL radiation property to the parameter such as the beam energy, the energy spread, the emittance, the peak current, the input seeding power, and the deflection parameter of undulators (radiators) have been studied by using GENESIS simulations.

INTRODUCTION

The recent developments of free-electron laser (FEL) based new generation synchrotron radiation sources in the x-ray domain enable to provide new insights on the matter investigations, thanks to the source properties. Indeed, new schemes such as the higher-harmonics seeding generated in the gases (HHG seeding) [1] and the echo-enable harmonic generation (EEHG) [2] provide a further control of the FEL pulse properties and access to short wavelength in a rather compact way. Another strategy to make the FEL sources be smaller is to replace a conventional linear accelerator (CLA) by a laser wake-field accelerator (LWFA) [3] (so-called 5th generation of synchrotron light sources), enabling to produce the electron beam of GeV regime in a plasma of cm length with the acceleration of GV/m and very short pulses of electron bunches [4].

The French project "LUNEX5" (free electron Laser Using a New accelerator for the Exploitation of X-ray radiation of 5th generation) aims at providing short and intense laser pulses in the soft x-ray region. This FEL comports either the CLA or the LWFA, and includes the HHG and EEHG options on the common FEL line. The FEL radiation covers the spectral range of 4 - 40 nm with the pulse duration of 20 fs.

LUNEX5 REFERENCE CASE

"LUNEX5" consists in the 400 MeV CLA with superconductive accelerator cavities or the 0.3 - 1 GeV LWFA, both providing short electron bunches to undulators. To achieve the soft x-ray especially with the advanced 4th generation light sources, the HHG and EEHG are adopted.

The CLA configures the superconductive L-band linac with a photo-cathode gun. It is designed for continuous-wave operation in the future. The LWFA will use the dedicated laser system of 200 TW with the laser power of either 10 PW from CILEX (Centre Interdisciplinaire de Lumière EXtrême) or 60 TW from LOA (Laboratoire d'Optique Appliquée). The FEL line comports in-vacuum undulators [5] with the magnetic fields of 1.5 T at the gap of 3 mm and the periodic length of 15 mm.

A Ti-Sapphire oscillator (the wavelength of 800 nm, the pulse duration of 30 fs), a regenerative and a multi-pass amplifier (the wavelength of 800nm, the pulse duration of 30 fs, the power of 10 mJ, the repetition of 50 Hz with the option of 1 kHz) will be used for the both seeding schemes. For the EEHG, the amplifier output is 3rd harmonic (the wavelength of 266 nm) and split in two parts, then injected. For the HHG, the amplifier output is injected directly to the gas cell. In the case of EEHG, the 266 nm seed laser is injected at the chicanes for EEHG, and the 20 - 40 nm HHG seed laser is injected at the entrance of the undulators in the case of HHG seeding (see Fig. 1 [5]).

These sensitivity studies to the parameters of FEL performance have been carried on a reference LUNEX5 case [6], developed for cascaded FEL of the wavelength of 20 nm with parameters given in Table 1 (the CLA case). The performances have been calculated by using

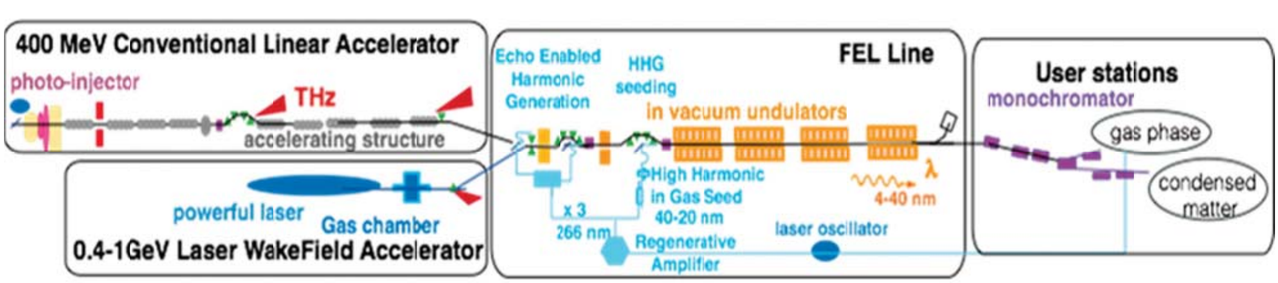

Figure 1: LUNEX5 scheme.

ISBN 978-3-95450-123-6

GENESIS 1.3 [7]. Figure 2 shows the results of the FEL peak power versus the radiator length to show the exponential growth followed by saturation at 10.89 m in the radiators. The final outputs of FEL properties such as the spectrum and temporal profile are illustrated in Fig. 3. The bandwidth and pulse duration are 0.03 nm (FWHM) and 5 μm (17 fs, FWHM) respectively.

Table 1: Electron Beam, Seed Laser, and Undulator Parameters Taken for the 20 nm Cascade Case

Electron beam	
Beam energy [MeV]	400
Relative energy spread	$2*10^{-4}$
Emmitance [π mm mrad]	1.5
Charge [nC]	1
Bunch length [ps (RMS)]	1
Peak current [kA]	0.4
Seed laser	
Wavelength [nm]	40
Peak power [kW]	10
Pulse duration [fs (FWHM)]	20
Undulator (modulator)	
Periodic length of magnets [mm]	15
Number of magnets in 1 segment	200
Number of segments	1
Deflection parameter	2.134
Resonant wavelength [nm]	40
Peak magnetic field [T]	1.53
Undulator (radiator)	
Periodic length of magnets [mm]	15
Number of magnets in 1 segment	200
Number of segments	3
Deflection parameter	1.067
Resonant wavelength [nm]	20
Peak magnetic field [T]	0.76

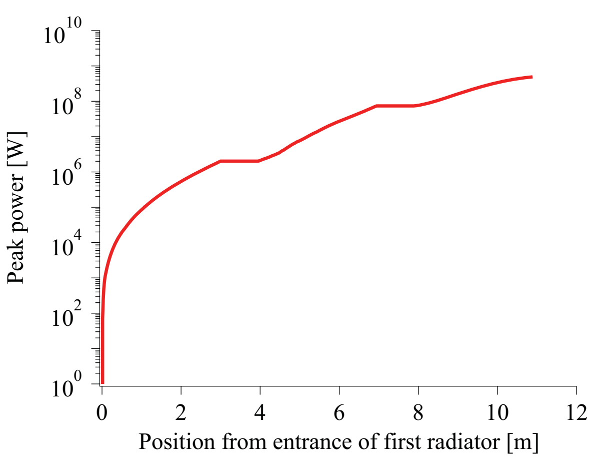

Figure 2: FEL peak power evolution calculated by GENESIS in the 20 nm cascaded FEL case.

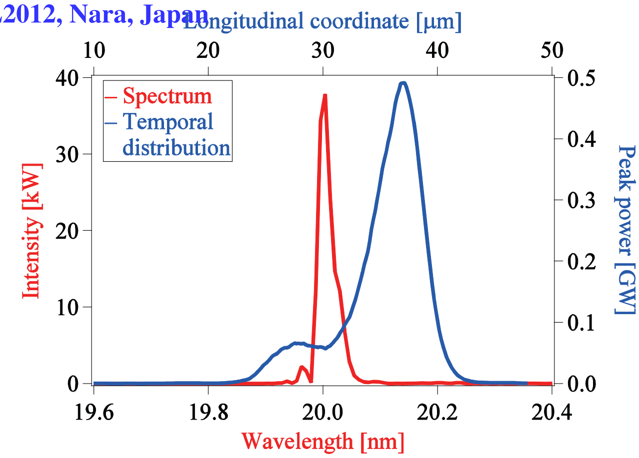

Figure 3: Spectral (red solid line) and temporal (blue solid line) distributions calculated by GENESIS in the 20 nm cascaded FEL case.

SENSITIVITY TO ELECTRON BEAM PARAMETERS

The sensitivity is studied for the FEL performances versus different electron beam parameters.

Figure 4 illustrates the FEL power dependences on the beam energy. Maximum power is achieved when the energy is well tuned to the resonant wavelength defined by the undulator magnetic fields. The decrease in peak power is sharper for higher energies because the gain decreases at shorter wavelength. A 10 % FEL peak power reduction from reference case sets a tolerance on the electron beam energy between -0.034 % and +0.065 % of the reference value (400 MeV).

Figure 5 illustrates the FEL power dependences on the energy spread. An increase of energy spread leads to a reduced gain and a smaller peak power. A 10 % FEL peak power reduction from reference case sets the tolerance on the energy spread of less than + 24 % of the reference value ($2*10^{-4}$).

Figure 6 illustrates the FEL power dependences on the emittance. An increase of emittance also leads to a reduced gain and a smaller peak power, such as the energy spread. A 10 % FEL peak power reduction from reference case sets the tolerance on the emittance of less than +4.9 % of the reference value (1.5π mm mrad).

Figure 7 illustrates the FEL power dependences on the peak current without changing of bunch length. The higher the peak current is increased, the higher the FEL peak power is also increased since more electrons participate to the process. A 10 % FEL peak power reduction from reference case sets the tolerance on the peak current of more than -3.3 % of the reference value (0.4 kA).

ISBN 978-3-95450-123-6

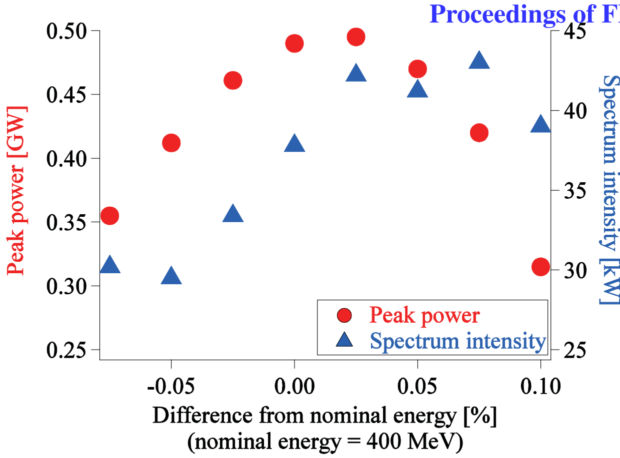

Figure 4: Power dependences on the beam energy in the 20 nm cascaded FEL case.
●: the peak power of the FEL pulse, ▲: the spectrum intensity.

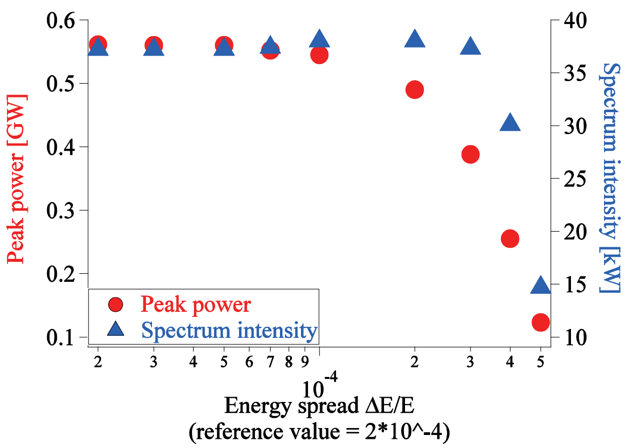

Figure 5: Power dependences on the beam energy spread in the 20 nm cascaded FEL case.
●: the peak power of the FEL pulse, ▲: the spectrum intensity.

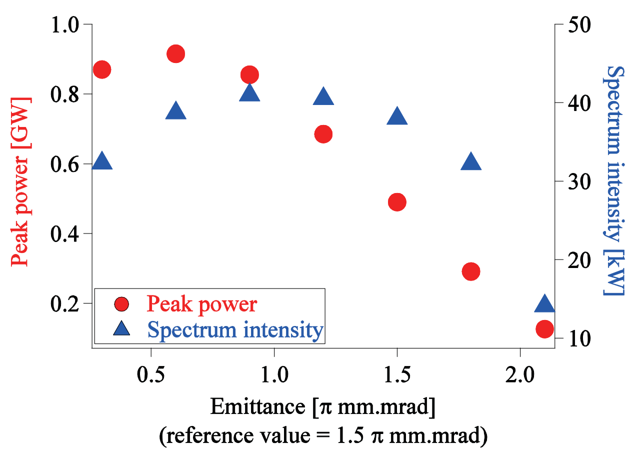

Figure 6: Power dependences on the beam emittance in the 20 nm cascaded FEL case. The matching condition at the undulators isn't changed from the reference case.
●: the peak power of the FEL pulse, ▲: the spectrum intensity.

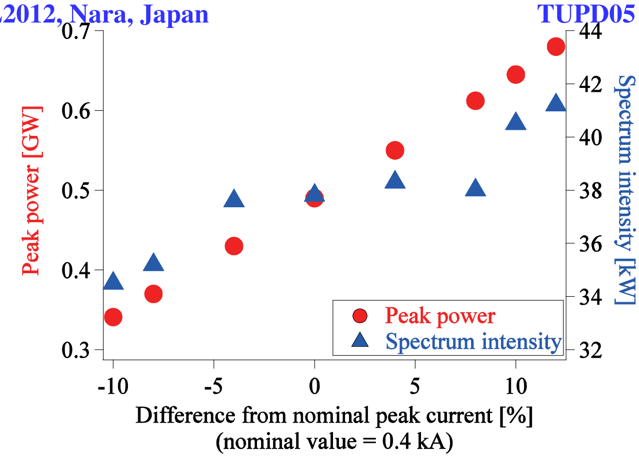

Figure 7: Power dependences on the peak current without changing of the bunch length in the 20 nm cascaded FEL case.
●: the peak power of the FEL pulse, ▲: the spectrum intensity.

SENSITIVITY TO SEEDING SOURCE PARAMETER

Figure 8 illustrates the FEL power dependences on the seed power without changing of the seed pulse duration. The higher the seed laser power increases, the higher the FEL peak power increases. The saturation is achieved at about 3 GW because the peak power doesn't change around the region of seeding power. As the results, a 10 % FEL peak power reduction from reference case sets the tolerance on the seed power of more than -38 % of the reference value (10 kW).

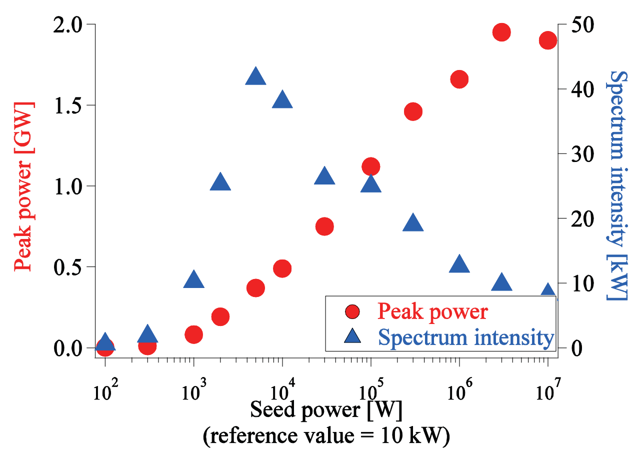

Figure 8: Power dependences on the seed power without changing of the seed pulse duration in the 20 nm cascaded FEL case.
●: the peak power of the FEL pulse, ▲: the spectrum intensity.

SENSITIVITY TO UNDULATOR PARAMETER

Figure 9 illustrates the FEL power dependences on the undulator deflection parameter of the radiators. A 10 % FEL peak power reduction from reference case sets the

ISBN 978-3-95450-123-6

tolerance on the deflection parameter of between -0.076 % and +0.22 % of the reference value (0.799).

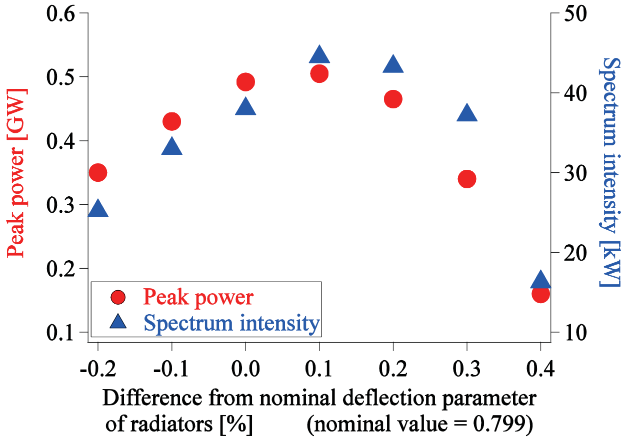

Figure 9: Power dependences on the deflection parameter of the radiators in the 20 nm cascaded FEL case.
●: the peak power of the FEL pulse, ▲: the spectrum intensity.

CONCLUSION

First parameters sensitivities of LUNEX5 have been studied by using GENESIS. Table 2 shows the summary of the obtained tolerances. The beam energy and the deflection parameter of radiators are drastically critical.

We continue to study the other parameters by using GENESIS and deepen the discussions toward the implementation of LUNEX5.

Table 2: Required Performance for the Variation of FEL Peak Power Less Than 10 % to the Reference Parameters Taken for the 20 nm Cascade Case; Electron Beam, Seed Laser, and Undulator Parameters

Electron beam	**Reference value**	**Tolerance**
Beam energy	400 MeV	-0.034 ~ +0.065 %
Energy spread	$2*10^{-4}$	Less than +24 %
Emmitance	1.5 π mm.mrad	Less than +4.9 %
Peak current	0.4 kA	More than -3.3 %
Seed laser		
Peak power	10 kW	More than -38%
Undulator (radiator)		
Deflection parameter	0.799	-0.076 ~ +0.22 %

ACKNOWLEDGMENT

The authors thank the DYNACO contract from the Agence Nationale de la Recherche (ANR).

REFERENCES

[1] G. Lambert et al., Nature Physics 4, 296-30, (2008); T. Togashi et al., Optics Express, 1, 2011, 317-324: C. Lechner et al., in these proceedings.
[2] G. Stupakov, Phys. Rev. Lett., 102, 074801 (2009); D. Xiang et al. Phys. Rev. Lett. 105, 114801 (2010).
[3] K. Nakajima, Nature Physics, 4 (2008) 92; H.-P. Schlenvoigt et al., Nature Physics, 4 (2008) 130-133; M. Fuchs et al., Nature Physics.
[4] T. Tajima et al., Phys. Rev. Lett. 43, 267-270 (1979) ; V. Malka et al., Nature Physics 4 447-453 (2008); E. Esarey et al., in these proceedings.
[5] C. Benaderrahmane et al., in these proceedings.
[6] C. Evain et al., in these proceedings.
[7] S. Reiche, "Genesis 1.3: a fully 3D time-dependent FEL simulation code," Nucl. Instr. and Meth. A 429 (1999) 243.