PROGRESS OF THE LUNEX5 PROJECT

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Abstract

LUNEX5 (free electron Laser Using a New accelerator for the Exploitation of X-ray radiation of 5th generation) aims at investigating the production of short, intense, and coherent pulses in the soft X-ray region. It comprises two types of accelerators connected to a single Free Electron Laser (FEL), enabling the most advanced seeding configurations: High order Harmonic in Gas (HHG) seeding and Echo Enable Harmonic Generation (EEHG) with cryogenic in-vacuum undulators. The 400 MeV Conventional Linear Accelerator (CLA) uses superconducting (sc) cavities, compatible with a future upgrade towards high repetition rate for investigating advanced FEL schemes. It will also enable multi-user operation by splitting parts of the macropulse into several FEL lines. A 0.4 - 1 GeV Laser Wake Field Accelerator (LWFA) will also be qualified in view of FEL applications, in the single spike or seeded regime. After the Conceptual Design Report, R&D has been launched on a cryo-ready 3 m long in-vacuum undulator, a variable strong permanent magnet quadrupole, Smith-Purcell and electro-optics diagnostics. A test experiment is under preparation for validating the computed beam transport from the LWFA.

INTRODUCTION

Several X-ray FEL's in the X-ray range at LCLS (USA) [1], SACLA (Japan) [2] and in the VUV/soft X-ray at FLASH (Germany) [3], SCSS Test Accelerator (Japan) [4] and FERMI (Italy) [5] are now under operation and provide unique sources for multidisciplinary investigations of matter. They can supply only a restricted number of beamlines. Superconducting RF (SRF) technology, besides providing the possibility to operate at a high repetition rate of interest for coincidence experiments for example, enables to produce long electron macro-pulses which can be split into different FEL branches, approaching thus a multi-user facility like synchrotron radiation light sources. A step forward will be provided by the start of the European XFEL [6].

GENERAL DESCRIPTION OF LUNEX5 PROJECT

LUNEX5 [7, 8] proposes to develop a demonstrator for investigating the production of short, intense, and coherent pulses in the soft X-ray region. It will comprise two types of accelerators (see Fig. 1): a sc linac for enabling high repetition rate and multi-user operation and a low repetition rate LWFA, to be qualified in view of FEL application. The common FEL line will apply the most advanced seeding configurations (HHG seeding, EEHG) and provide flexibility. To assess the performance of these sources from a users' perspective, the facility will include a photon transport beamline equipped with an optional monochromator. This beamline will serve two end stations, which are optimized for experiments with gazeous and solid samples, respectively. The precise required equipment will be identified in close collaboration with the growing French XFEL user community, which is organized within the XFEL-Science research network and financially supported by the CNRS. User representatives will also participate in defining the science vision going beyond the LUNEX5 demonstrator project towards the needs for a further full scale facility.

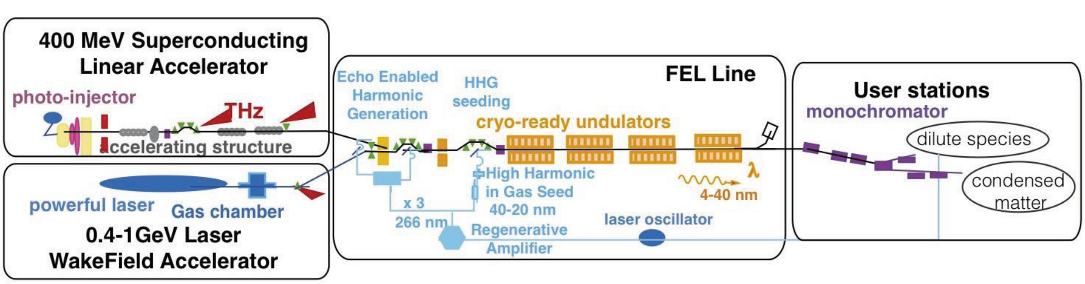

Figure 1: LUNEX5 scheme.

ISBN 978-3-95450-143-4

THE SUPERCONDUCTING LINEAR ACCELERATOR

For the 400 MeV LUNEX 5 CLA, two options were considered and compared, normal conducting (nc) S-band at 3 GHz versus superconducting (sc) L-band at 1.3 GHz. It quickly came out that the latter was more attractive, achieving better performance for comparable investment and operational costs in pulsed operation and moreover, providing the possibility of further upgrading towards CW operation. It allows achieving average current, several orders of magnitude larger than the nc version. Therefore we assumed as base line the use of the SRF technology developed for XFEL [9], slightly modified in order to ensure a safe CW operation [10, 11, 12]. The 12 m long XFEL type cryomodule (CM) houses a string of height 9-cell cavities, each equipped with an adjustable antenna input power coupler, two HOM dampers and a monitoring pick-up; their frequency tuning is ensured by a motor driven mechanism, which changes the cavity length and fast piezo-tuners, aimed at controlling the microphonics. A layout of the CLA is shown in Fig. 1. It will be built in two phases (Table 1). The phase 1 SRF system will be designed for pulsed operation up to 10 % duty cycle, namely 100 bunches per macropulse of 500 µs flat-top at 50 Hz max. repetition rate. Only two CM's operating at 24 MV/m will be first implemented, which requires an overall cryogenic power of ~ 120 W at 2K, including the 3rd harmonic CM. In phase 2, for CW operation, the implementation of a third CM will reduce the accelerating gradient from 24 down to 16.5 MV/m, hence keeping the cryogenic load at a reasonable level (< 500 W at 2K). For this purpose, the phase 1 cryogenic system will be upgraded by installing 3 staged cold compressors, additional exchangers and an intermediate turbine. One RF transmitter and LLRF system will be used for each cavity in order to achieve a high stability in phase and amplitude. Solid state amplifiers, capable of delivering up to 20 kW CW at 1.3 GHz, providing modularity and low phase noise, will be developed at SOLEIL. The gun will be a normal conducting 1.3 GHz PITZ type photo-gun [13] (1 π.mm.mrad total transverse normalized emittance, 1 nC, 60 MV/m accelerating voltage, 20 ps flat top laser profile), powered with a 10 MW multibeam klystron, pulsed by a commercial solid state modulator. For repetition rate much higher than 1 kHz in CW mode, a new type of gun will be required. There are essentially two types of low emittance gun allowing for repetition rate at the MHz level, either a nc VHF photo-gun [14], or a sc L-band one [15].

ASTRA [17] simulations along the RF-gun and the first CM, up to about 200 MeV, exhibit total transverse emittances of the order of 0.9 π.mm.mrad for 1 nC bunch and about 50 A peak current. A magnetic compressor, located just downstream of the first CM, further increases the peak current. The emittance grows moderately up to 1.22 π.mm.mrad (calculation with CSRtrack [18]), mainly because of the Coherent Synchrotron Radiation in the S-chicane compressor. A third harmonic CM (16.5 MV/m) in opposite phase linearizes the longitudinal phase space profile, leading to 500 A peak current. The second CM running on crest enables to reach 400 MeV; it is followed by a long free section for an optional third CM, an anachromatic dogleg dedicated to collimation and a matching section for the downstream undulalors. Beam performances are shown in Fig. 2.

Table 1: The two phases of the LUNEX5 CLA (P_1, P_2 and P_t are the 1.3 GHz CM, the 3rd harmonic CM [16] and the overall cryogenic load, respectively.

Mode	Nb of CMs	E-field [MV/m]	Q_o [10^{10}]	P_1 [W] at 2K	P_2 [W] at 2K	P_t [W] at 2K
Pulsed ~10%	2	25	1.0	55	10	120
CW	3	16	1.5	140	80	500

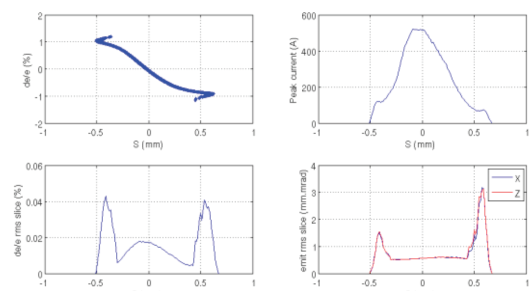

Figure 2: Longitudinal chirped phase space and slice parameters along the bunch in the undulator section at 400 MeV, (1 nC).

ADVANCED FEL LINE

Advanced FEL searches both control of the spectral and temporal properties and more generally the longitudinal coherence, and frequency multiplication for a compact FEL line. After the first Coherent Harmonic generation experiments in the VUV [19-21], seeding with conventional laser has demonstrated the suppression of the spikes, the reduction in gain length and an increase in coherence [22]. Efficient up-frequency conversion can be achieved either by High Gain Harmonic Generation in cascade [23] or with the Echo Enable Harmonic Generation (EEHG) scheme [24-26]. Short wavelength seeding with High order harmonic generated in gas has been efficiently operated [27-30]. Self-seeding efficiently cleans the SASE spectrum [31-33].

The FEL line comprises transport magnetic elements, dump dipole and cryo-ready in-vacuum undulators with periods of 30 (modulators) or 15 mm (PrFeB cryogenic radiators) [34]. A 3 m long 15 mm period cryogenic undulator with PrFeB magnets is under construction, relying on the SOLEIL experience of the construction of a first PrFeB 2 m long cryognenic undulator, presently installed on the ring [35]. A Ti-Sa oscillator (30 fs @ 800 nm), followed by a regenerative and a multipass amplifier (30 fs, 800nm, 10 mJ, 50 Hz, option at 1 kHz) will be used in both seeding schemes. For the Echo, the amplifier output is tripled (266 nm) and split into two parts. For High Harmonic generated in Gas, the amplifier output injects directly the gas cell.

TOWARDS A LWFA BASED FEL DEMONSTRATION

With respect to conventional accelerators, LWFA beams exhibit very different characteristics of phase space: in longitudinal, short bunch duration and large relative energy spread and in transverse, large divergence and micrometer size [36]. An electron beam of 1 % energy spread, 1 mrad divergence, 1 mm size, 4 kA peak current is first strongly focused in variable permanent quadrupoles, a prototype of which is under study; then it enters a magnetic chicane for sorting the electrons in energy, enabling to reduce the slice energy spread down to 0.1 % while lengthening from 2 fs to 20 fs; thereafter it is transported in a second triplet of quadrupoles for focusing one slice after the other through the undulator [37]. A demonstration test experiment targeting 200 nm is under preparation with the 60 TW laser of the Lab. d'Optique Appliquée and either the 3 m long cryogenic undulator or a 2 m NdFeB U20 undulator.

CONCLUSION

LUNEX5 R&D with specific funding has started. Complementary studies with respect to the CDR include sensitivity to the parameters for FEL sources. A new transport of the electron beam from a LWFA to the undulator enables theoretical FEL amplification with more realistic parameters. R&D on the components is also launched such as for the 3 m long cryo-ready undulator and for some diagnostics.

ACKNOWLEDGMENTS

The authors would like to acknowledge funding from ANR (DYNACO, SP), Triangle de la Physique (QUAPEVA, RASYCO), the French Swedish collaboration and the ERC, Sigmaphi collaborators for the QUAPEVA contract. M. E. Couprie also thanks E. Wallen collaborator for the joint French-Swedish work on insertion devices.

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