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Report on the Eurizon 2020+ workshop on FEL linac driver and FEL physics applications

1 Introduction

A workshop including FEL developers and possible users was held at the European XFEL premises, in Schenefeld, Germany as part of the Eurizon 2020+ task 4.4, D.4.20 (M48). Task 4.4 involved INFN, European XFEL and DESY and consisted of a collaborative study on a 6 GeV Linac based on S-C band technology to serve as a Free-Electron Laser (FEL) driver and, potentially, as a top-up injector for synchrotron X-ray storage rings.

The workshop served to disseminate the results of the study but also as a general introduction to newcomers in the field of particle accelerators, FELs and scientific applications of FELs. It was held at the European XFEL premises as a one-day event taking place on Tuesday January 23rd, 2024, on the same week and as part of the joint DESY and European XFEL Users' Meeting and satellite workshops, thus allowing the participants to profit from extended scientific events and extensive networking.

Young scientists from Ukraine and Eastern Europe were especially welcome to join and funding was allocated to cover all expenses for the participation to the workshop and to the joint DESY and European XFEL user meeting for 8 Ukrainian and Easter European scientists, with special attention to young individuals from institutions that can profit from it and from the unique networking opportunity given. A total of 57 participants registered to the workshop, with a peak of 30 participants in person.

In order to maximize participation from Ukrainian-based scientists, remote participation was made possible, i.e. the workshop took place in hybrid mode from the very beginning. The event was preceded by a special seminar (held at the DESY premises, and also in hybrid form) by Prof. Vasyl Maslov, from the National Science Center Kharkiv Institute of Physics and Technology, Kharkiv, Ukraine discussing plasma wakefield acceleration with externally injected and self-injected electron beams, which in the future may be used as FEL drivers in place of conventional linacs, [1].

After a short introduction given by Serguei Molodtsov and Gianluca Geloni (European XFEL), the following topics were discussed during the workshop:

1. Introduction to linear electron accelerators and X-ray Free-Electron Lasers
2. Results from the Eurizon 2020+ project: linac and FEL driver investigations
3. Scientific Applications of X-Ray FELs: the European XFEL instruments

2 Introduction to linear electron accelerators and X-ray Free-Electron Lasers

The session consisted of introductory talks to linear particle accelerators (Anna Giribono, INFN) and X-ray Free-Electron Lasers (XFELs) working principles (Fabian Pannek, Hamburg University and European XFEL). The aim of these talks was to give a minimum background for the non-expert participants, in order to allow them to follow the more technical discussion in the following session and to build a foundation for the application session.

In the talk about linear particle accelerators, Anna Giribono gave a primer on linear electron accelerators. The presenter introduced the physics of linear particle accelerators, providing a comprehensive overview of key themes and fundamental concepts in this advanced field of particle physics. The seminar aimed to establish a solid foundation for understanding the basic principles, technologies involved, and practical applications of linear particle accelerators in fields such as medicine, nuclear research, and high-energy physics. The presentation began with a historical overview, examining the development of linear particle accelerators in the context of scientific research and applications. Subsequently, the seminar focused on the underlying physical principles of such accelerators, exploring concepts of charged particle dynamics and describing key components of a linear particle accelerator such as particle sources, accelerating structures, beam transport magnets and so on. Throughout the seminar, critical technologies for the design and operation of linear accelerators were examined. Finally, the description of few facilities based on linear accelerators has been provided. In details, the schematic layout of the accelerator of the EuropeanXFEL, Swiss FEL, CompactLight and EuPRAXIA@SPARC_LAB has been widely discussed.

During the talk about XFEL working principles, Fabian Pannek explained how an X-ray Free-electron Laser works. After a brief historical overview of synchrotron light sources, FELs were introduced as amplifiers, and the amplification mechanism was discussed. The simplest 1D Steady-state FEL model was then proposed with the limit of high-gain

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FEL, followed up by a simple treatment of exponential region and saturation. SASE was introduced in relation with the FEL initial condition. Further on, a basic discussion on SASE radiation characteristics including statistics, spectrum and time domain was given. Finally, the European XFEL facility was presented.

3 Results from the Eurizon 2020+ project: linac and FEL driver investigations

The session consisted of two talks reporting and disseminating the results obtained in the framework of the Eurizon 2020+ project. The results of these studies are discussed more thoroughly in the corresponding Milestone.

Anna Giribono discussed studies made on a 6 GeV Linac as FEL driver and storage ring injector featuring two distinct operational solutions. The first configuration utilizes a C-band traveling wave linac, enabling the generation of Free-Electron Laser (FEL) radiation within the nanometer wavelength range. The second configuration is tailored for injection into a storage ring, employing an S-band linac with biperiodic standing wave accelerating cavities.

The presentation delves into the technical aspects of both linac configurations, providing insights into the design, construction, and operation of the accelerator system. The C-band traveling wave linac is optimized for the efficient generation of FEL radiation and for the production of electron beams with 250 pC charge,up to 5 kAmp peak current, less than 0.6 mm-mrad slice normalized transverse emittance and less than 2 MeV slice energy spread. Concurrently, the S-band linac has been explored explored, emphasizing its role in providing 250 mAmp electron beams for injection into a storage ring with 1.5 transverse emittance and less than 0.35 % energy spread.

Following the report on the linac, Fabian Pannek discussed the results of theoretical investigation on X-ray FEL pulse characteristics that may be obtained using the linac as an FEL driver. Ming-Xie parameterization using the 6 GeV beam from the linac was performed as a first step.

Special attention has been given on the spectral range between 50 eV and 1000 eV. Since 85% of the earth crust is made out of oxides, being able to study the O K-edge and the 3d L-edges and therefore to disentangle the properties of these materials is extremely important. Going up to 1 keV will allow to study 3d transition metals and their oxides and related physical phenomena like ferroelectricity, high T_c superconductivity and spin transitions. These are the keys to develop new technologies related to societal challenges.

On the other side of the spectrum, the study of lithium as well as two photon excitation on the O, N and C-edges would also be of interest. For instance, considering Oxygen, new dissociation pathways and dynamics could be studied for all oxygen containing molecules, such as H2O and the same motivation would make two-photon excitation around the C- (140-150eV) or N- (200 eV) edge also worthwhile.

These motivations, together with the relatively high electron energy that allow one to produce highly energetic pulses motivate the before-mentioned energy range between 50 eV and 1000 eV. Ideal simulations as well as start-to-end simulations based on the linac studies were presented, including statistics, gain curve, longitudinal temporal profile, spectrum and transverse distribution. Compatibility with special modes (e.g. short pulses, multiple colors, self-seeding) is granted (at the repetition rate of the driver).

4 Applications of X-Ray FELs – The European XFEL instruments

During the final session of the workshop, a thorough introduction on applications of X-ray FELs was given taking as practical example the instruments of the European XFEL. This session was especially conceived to introduce our guests and students to the science that is currently done at the European XFEL, also in view of the joint European XFEL and DESY Users' Meeting, which unfolded in the following days.

The European XFEL features three undulator lines, SASE1 and SASE2, dedicated to the generation of hard X-rays, and SASE3, dedicated to the generation of soft X-rays. SASE1 and SASE2 host, altogether, four instruments, while SASE3 hosts three instruments. All the instruments were introduced by beamline scientists and leading scientists at the European XFEL.

As concerns SASE1, the SPB/SFX instrument, dedicated to ultrafast coherent diffraction imaging of single particles, clusters and biomolecules as well as to the structure determination of single particles and serial femtosecond crystallography was discussed by Chan Kim, while Mykola Biednov introduced science opportunities at FXE (Femtosecond X-ray Experiments), which is dedicated to time-resolved investigations of the dynamics of solids, liquids, gases.

For SASE2, Ulrike Bösenberg treated the Material Imaging and Dynamics (MID) instrument, which is dedicated to structure determination of nanodevices and dynamics at the nanoscale. Following this talk, the HED (High Energy Density) instrument and its capabilities for investigating matter under extreme conditions using hard X-ray FEL radiation, e.g. probing dense plasmas was discussed by Ulf Zastrau.

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SASE3 currently hosts three instruments. Tommaso Mazza discussed the SQS (Small Quantum System) instrument for the investigation of atoms, ions, molecules and clusters in intense fields and non-linear phenomena. Andreas Scherz introduced the SCS (Spectroscopy and coherent scattering) instrument, and various opportunity for the investigation of electronic structure dynamics of strongly correlated materials, liquids and nano-systems using soft X-rays. Finally, Manuel Izquierdo introduced the Soft X-ray Port (SXP), which deals with electronic and atomic properties of condensed matter systems at surfaces and interfaces using time resolved photoelectron spectroscopy in the soft x-ray regime.

5 Conclusions

The workshop met its goals of disseminating the results of the studies on the 6GeV linac, as well as to serve as an introduction for young students, with special attention to Eastern European and Ukrainian colleagues. The workshop page can be found at [2]

References

[1] Vasyl Maslov. Plasma Undulator and Plasma Wakefield Acceleration with Externally Injected and Self-injected e-Beams, https://indico.desy.de/event/41899/page/4731-satellite-meetings.

[2] Eurizon 2020+ workshop on FEL linac driver and FEL physics applications, https://www.xfel.eu/users/user_events/users__meetings/2024_users__meeting/satellite_meetings/tuesday_23_january_2024___eurizon_2020_workshop_on_fel_linac_driver_and_fel_physics_applications/index_eng.html .

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