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FLASH2020+ PROJECT PROGRESS: CURRENT INSTALLATIONS AND FUTURE PLANS

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Abstract

The FLASH2020+ project has started to transform the FLASH facility to broaden the facility profile and meet demands of future user experiments. In a nine-month lasting shutdown until August 2022 the linear accelerator of the FLASH facility has, among others, been upgraded with a laser heater, new bunch compressors and new modules. The latter results in an energy upgrade to 1.35 GeV allowing to reach sub 4 nm wavelength. In the following 14-month lasting shutdown starting mid 2024 the FLASH1 FEL beamline will be completely rebuild. The design is based on external seeding at MHz repetition rate in burst mode allowing for coherent tuneable FEL radiation in wavelength and polarization by installation new APPLE-III undulators. Post compression of the beam downstream of the radiators will allow for high quality THz generation and together with the new experimental end stations and pump probe lasers provide a unique portfolio for next generation user experiments.

INTRODUCTION

The FLASH facility [1-3], housed at DESY, Hamburg, currently consists of a superconducting linac powering two FEL beamlines (FLASH1 and FLASH2). These beamlines provide extreme ultraviolet to soft x-ray radiation generated via self-amplified spontaneous emission (SASE) to facilitate various kinds of user experiments. In addition, a significant share of the FLASH operation time is committed to research and development, which e.g. led to developments like the gas monitor detector for FEL beam position and intensity diagnostics [4]. The developed components in R&D also contributed significantly to upgrades and improvements the facility has undergone since it was built in 2003/2004, at that time named VUV-FEL at TTF2 [5]. To increase the available parameter range and enable next generation user experiments the current facility upgrade, coordinated in the FLASH2020+ project, has already been started. One of the main goals is to provide coherent and spectro-temporally stable beams while also extending the wavelength range even further into the water window.

The individual updates required to achieve the project milestones are grouped in a two-stage process: During a nine-month shutdown which finished in mid-August 2022 the linac has been in focus with upgrades targeting the beam quality and energy, described in detail in the following. The second stage will target the current FLASH1 FEL beamline, removing all of its components and replacing it by an externally seeded beamline. The latter includes an upgrade of the existing photon diagnostics and photon beam transport to allow for most efficient use of beamtime by users with fully characterised beams for every shot at highest possible intensities.

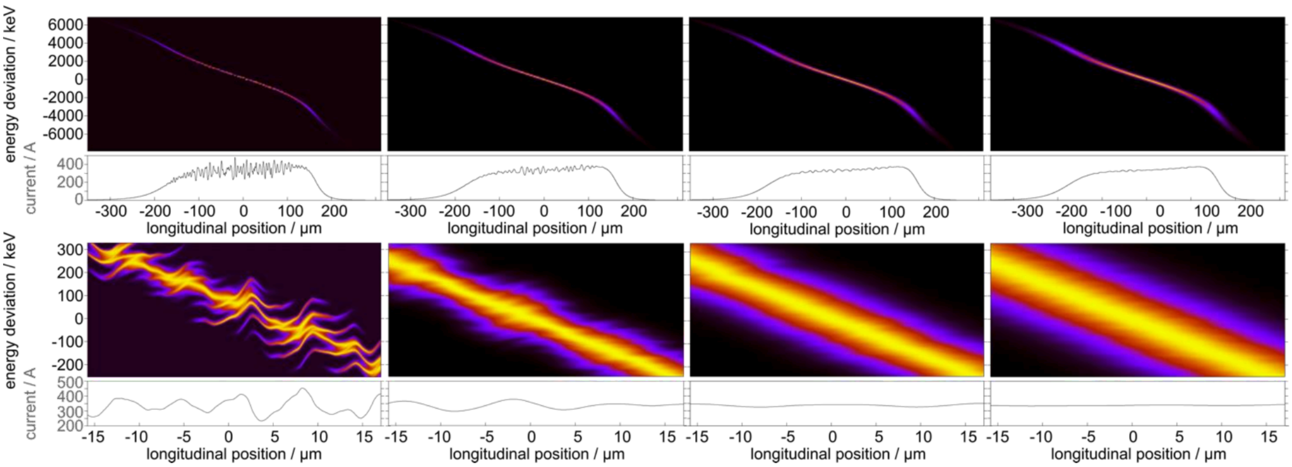

Figure 1: Numerical simulation of the phase space of the full electron beam (top) and the central slice (bottom) together with the current profile at the end of the linac using a recently developed semi-Lagrangian Vlasov simulation code [6]. The images on the left display the situation with the laser heater at zero laser power resulting in an initial sliced energy spread of 3 keV before compression. Towards the right the laser power is increased to reach sliced energy spreads of 5

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keV, 7 keV and 9 keV respectively. The current profiles visualise how the increased slice energy spread reduces the micro bunching while also increasing the characteristic wavelength of the features

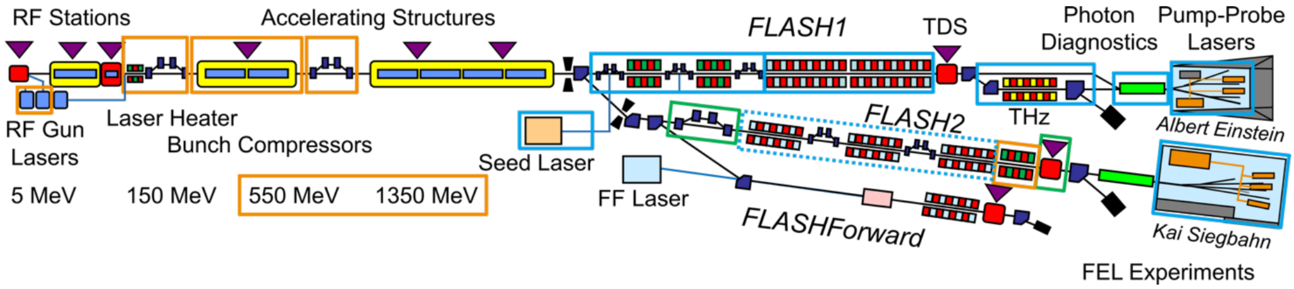

Figure 2: Schematic drawing of the FLASH facility with the accelerator section on the left starting at the gun (red square) the electron is accelerated to 150 MeV in the first modules (ACC1, yellow and ACC39, red) before being overlapped with a laser in the laser heater and then compressed in the first bunch compressor. In the now new modules (ACC2 and ACC3, yellow) the beam is then brought to 550 MeV and further compressed in the second bunch compressor. The final beam energy, currently determining the wavelength of the FEL radiation in FLASH1, is then adjusted using the following modules (ACC4 ,5, 6 and 7, yellow). Downstream of the accelerator the portions of the bunch train beam can be distributed into the FLASH2 or Flash-forward beamline and in parallel to FLASH1. For the FLASH1 beamline the schematic already illustrates the seed beamline while for FLASH2 a future upgrade option for generation of ultrashort pulses is displayed. Upgrades of the FLASH 2020+ project are illustrated in coloured boxes with green already being in operation, orange installed in the current shutdown and blue upgrades to be implemented starting 2024.

FIRST INSTALLAION PHASE 2021-2022

With the FLASH2 FEL beamline being the most recent addition to the FLASH user facility, which already got retrofitted with a dedicated bunch compressor and a transverse deflecting structure, called PolariX [7], to increase diagnostic capabilities and electron beam quality the accelerator was at highest priority for the current upgrade phase. In the nine-month lasting shutdown until August 2022 the linear accelerator has undergone severe modification to enhance the electron beam properties and increase the available parameter range for users, especially towards short wavelengths. Starting with the electron generation at the gun, two new photo injector lasers systems have been installed allowing for more independent control of the bunch train parts being sent to the FEL beamlines. Tweaking of the laser pulse duration and the spot size on the cathode will allow operation with tailored electron beam properties. This will enable for example the generation of THz at highest bunch charges in FLASH1 while providing short pulses with low charge in FLASH2. The old photoinjector lasers, which are approaching the end of their lifetime, will still be used to bring the facility back in operation at the end of the shutdown and serve as a backup after commissioning of the new systems.

Downstream of the superconducting acceleration modules ACC1 and the phase space linearizing module ACC39 the completely redesigned first compression and matching section now also incorporates a laser heater. In contrast to other designs [8], here, the laser heater acts on the non-dispersed electron beam to avoid transverse nonuniformities. Simulations of this system show an effective decrease in the beam substructure induced by micro bunching for mildly increasing the initial sliced energy spread from 3 keV to about 9 keV [9]. While microbunching is a gain process with a stochastic seed originating from noise, the laser heater allows to control the gain and thus flattens the current profile of the resulting electron beam, as can be seen in Fig 1. Since for external seeding a fine controlled substructure will be imprinted on the beam starting from a reproducible and homogenous current profile is crucial to deliver stable FEL output to user experiments. In addition to heating the entire electron bunch more elaborate schemes are also being investigated.

For increasing the maximum electron energy of FLASH, the two acceleration modules downstream of the first bunch compressor called ACC2 and AAC3 have been replaced by new state-of-the-art modules and the RF distribution has been optimised. As a result, the former XFEL prototype modules will allow operation at average gradient close to 30 MeV/m and thus increase the possible electron beam energy by 100 MeV to a total of 1.35 GeV. The higher electron energy in turn allows to generate higher photon energies and provide the users with sub 4nm photon wavelengths in the fundamental, extending the feasible experimental applications. In FLASH2 additionally the installation of a short period afterburner, foreseen for the year 2023, will allow to boost intensity at the third harmonic and thus facilitate experiments at wavelength as low as 1.39 nm. The design of the afterburner follows the APPLE III principle allowing for variable polarisation accessible to experiments for the first time at FLASH.

Although not bound to the times of an accelerator shutdown the occasion is also used to expand and upgrade the installations in the experimental halls in parallel. New beamline components, e.g. for the time-delay compensating monochromator beamline FL23 in the FLASH2 experimental hall "Kai Siegbahn", have been prepared and put in place while in the FLASH1 hall "Albert Einstein" the existing pump-probe laser hutch undergoes an extensive refurbishment. Here, a new air-condition system will reduce temperature and humidity fluctuations providing an environment for stable operation of the 10 Hz millijoule laser system to be reinstalled. The project is progressing well, and all shutdown-related milestones were reached in time ensuring a smooth transition into the upcoming commissioning phase starting mid-August. With a very dense commissioning schedule ahead the whole FLASH team is looking forward to see the improvements also transferring to successful user campaigns starting in early November 2022. The following period of 2.5 years of user experiments as well as own R&D and preparatory seeding experiments using the new installed hardware will allow to further optimize and tweak the machine, also ensuring a smoother commissioning phase after installation of the seeded beamline.

SECOND INSTALLATION PHASE: FLASH1 - A NEW EXTERNALLY SEEDED BEAMLINE

The second stage of the FLASH2020+ project is focussed on the FLASH1 FEL beamline. In a 14-month shutdown period starting mid 2024 the complete existing beamline will be disassembled and removed from the accelerator tunnel. Once empty the infrastructure of the accelerator tunnel will be modernised and adjusted to host a new externally seeded FEL beamline, of which details are discussed in a separate contribution [10-12]. In short, using the concepts of echo-enabled harmonic generation [13] and high gain harmonic generation [14] and a newly developed 1 MHz burst tuneable seed laser in the range from 297 nm to 317 nm [15,16] coherent FEL radiation from 60nm down to 4nm can be generated. With the experience from the FLASH 2 afterburner the radiators for the new FLASH1 beamline will also follow the APPLE III concept and allow users to scan polarisation during experiments.

Downstream of the new radiators the generated FEL pulses are separated from the electron beam and passed over a new photon diagnostic section before being passed into the FLASH1 experiment hall "Albert Einstein". From the separation point the electron beam is passed via an additional bunch compressor into the THz undulator where radiation between 1 and 300 THz can be generated and also transported into the “Albert Einstein” hall for experiments. The post compression is a necessity of the drastically different bunch properties conducive for seeding with not fully compressed bunches with peak current around 500A and highly compressed bunches with highest possible peak current to allow for generating THz intensities on the 100 microjoule level. bunch properties conducive for seeding with rather long bunches with peak current around 500A and short bunches with highest possible peak current to allow for generating THz intensities on the 100 microjoule level.

On a similar note, the FLASH facility will be unique in operating an externally seeded beamline at FLASH1 and in parallel a SASE beamline at FLASH2 sharing the same linac. Also, here the different bunch properties required by the two mechanisms are challenging to be realised for parallel operation. A first proof-of-principle experiment has been conducted at the FLASH facility already in 2021 demonstrating the feasibility of parallel operation for the first time worldwide. Results are being presented in a separate contribution [17].

To fully exploit the beam properties of the seeded FEL also the Albert Einstein hall will experience further upgrades. Here, new pump-probe lasers with increased repetition rate, higher pulse energy and an increased wavelength portfolio will be made available to all beamlines. For elaborate pump-probe experiments a new beamline called FL11 will be installed which is optimised for highest transmission at short wavelengths and which allows to combine FEL, pump-probe laser and THz radiation at the end station. While using the FEL at other end stations, here experiments combining THz and Pump-probe laser can be performed in parallel.

Additional Upgrades Within the Project

As already indicated in Fig. 2, the upgrade plans within the FLASH2020+ project, e.g. with installations for generation of attosecond pulses at FLASH2, span beyond what can be described here and are subject to availability of additional funding. They will be presented in detail when more robust information is available.

CONCLUSION

With the current accelerator upgrades and the future installation of a 1 MHz repetition rate externally seeded beamline in burst mode the FLASH facility will significantly broaden its parameter set available to users. This creates opportunities for new kinds of user experiments and especially with the planned stability of the seeded FEL will allow for new classes of experiments not possible at FELs before.

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