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FIRST DEMONSTRATION OF PARALLEL OPERATION OF A SEEDED FEL AND A SASE FEL

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Abstract

The FLASH facility houses a superconducting linac powering two FEL beamlines with MHz repetition rate in 10 Hz bursts. Within the FLASH2020+ project, which is taking care of facility development, one major aspect is the transformation of one of the two FEL beam lines to deliver externally seeded fully coherent FEL pulses to photon user experiments. At the same time the second beam line will use the SASE principle to provide photon pulses of different properties to users. Since the electron beam phase space conducive for SASE or seeded operation is drastically different, here a proof-of-principle experiment using the existing experimental seeding hardware has been performed demonstrating the possibility of simultaneous operation. In this contribution we will describe the setup of the experiment and accelerator. Finally, we will discuss the results and their implications also for the FLASH2020+ project.

INTRODUCTION

FLASH, the Free-Electron Laser user facility in Hamburg, has been delivering high brilliance soft X-ray FEL pulses for user experiments since 2005 [1, 2]. Also, FLASH had been equipped with hardware to study seeded FELs [3]. To address the growing demand of beam time requests, the facility has been upgraded with a second FEL beam line in 2014 [4]. The next upgrade project, FLASH2020+ [5, 6], aims for several augmentations of the facility. Two key components are the higher electron beam energy of now 1.35 GeV and the implementation of external seeding, namely HGHG [7, 8] and EEHG [9] at the high repetition rates FLASH can offer.

Experimental Setup Within the User Facility

The FLASH FEL, as seen in Fig. 1, is driven by a superconducting linear accelerator and can provide up to 800 electron bunches, separated by 1 µs per so-called macro pulse. The bunches can be divided between FLASH1 and FLASH2 during each macro pulse, expending about 50 µs of the burst. This also allows for different RF-parameters for the two bunch trains. The macro pulses are generated at a repetition rate of 10 Hz. In the FLASH1 electron beam line, just upstream the SASE undulators, the experimental seeding hardware called Xseed is located. The setup consists of a seed laser injection where two seeds of a wavelength of 267 nm are coupled in the last dipole of the energy collimation area. For the laser-electron interaction, two planar electromagnetic modulators of orthogonally oriented deflection planes are used, separated by a dispersive chicane of sufficient strength for EEHG seeding. A second, less strong dispersive section completes the modulation section. The electron beam then passes to 10 m of radiator undulators, before the generated radiation is reflected into a diagnostic section inside another chicane. The electron beam is transported through a transverse deflecting structure and dipole magnet before it hits a screen and finally a diagnostic beam dump. During user operation none of the aforementioned components are influencing the beam. Due to the limited repetition rate of the used laser system only one bunch per macro pulse can be used for experimental seeding, while the remaining burst can be used for FLASH2.

EXPERIMENTAL SETUP

The experimental program to achieve parallel operation as a side goal was conducted in June 2021. The parameters used for the demonstration of true parallel operation can be found in Table 1.

Table 1: Parameters Used During the Demostration of Parallel Operation

Electron bunch		
Energy	E	685 MeV
Charge	C	400 pC
Duration	$\tau_{\mathrm{e,rms}}$	391 fs
Peak current	A_{peak}	770 A
Norm. emittance	ε_{x}	0.68 mm mrad
	ε_{y}	0.48 mm mrad
Mismatch para.	μ_{x}	1.10
	μ_{y}	1.07
Mismatch ampl.	M_{x}	1.56
	M_{y}	1.44
Dispersion	D_{x}	≤ 5 mm
	D_{y}	≤ 10 mm
Seed laser		
Wavelength	λ_{seed}	267 nm
Duration	$\tau_{\mathrm{seed,fwhm}}$	200 fs

Six-Dimensional Overlap

The six-dimensional overlap between electron bunch and seed laser pulses at each modulator is achieved by first using

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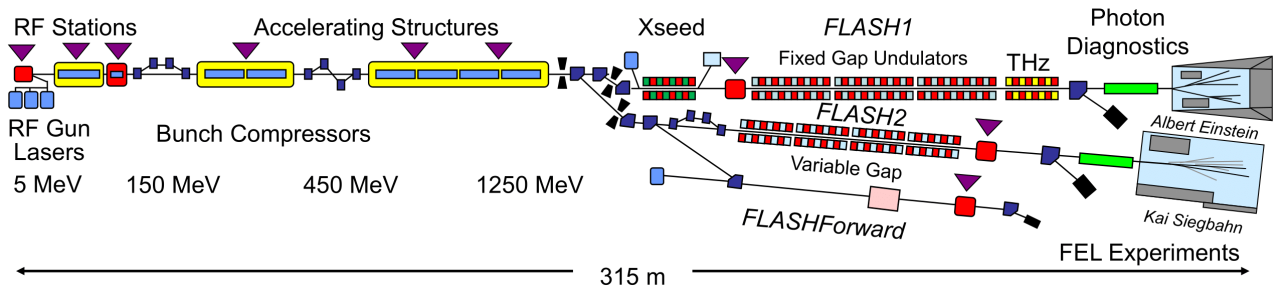

Figure 1: Layout of the FLASH user facility at the time of the experiment in 2021.

screens upstream and downstream of the respective modulator to find spatial overlap. The spectral overlap is ensured by exciting the electromagnetic modulators to the correct currents and tuning the radiator gaps for the correct wavelength of the 7th harmonic of the seed laser. Then the timing between electron beam and seed laser is scanned until the interaction is observable on the image of the transverse deflecting structure as in Fig. 2.

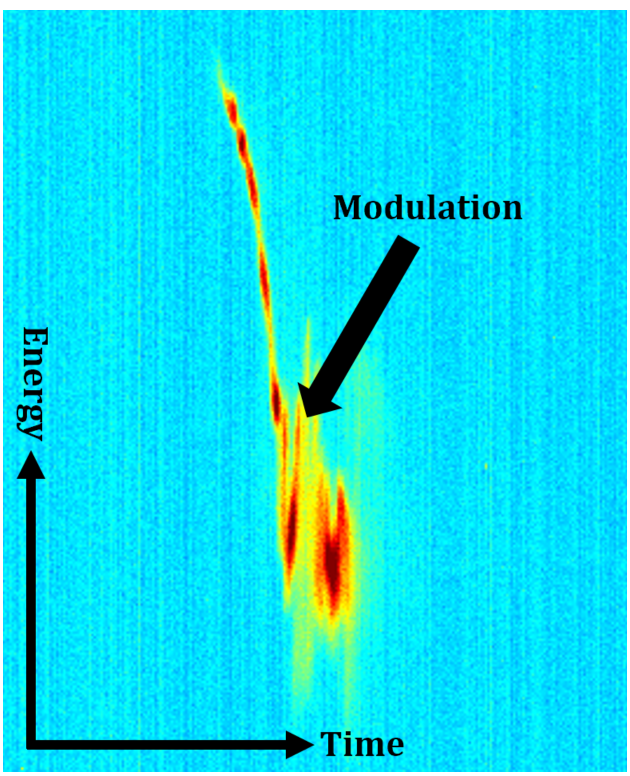

Figure 2: Image of the longitudinal phase-space distribution of the electrons within the bunch after passing the transverse deflecting structure and spectrometer dipole.

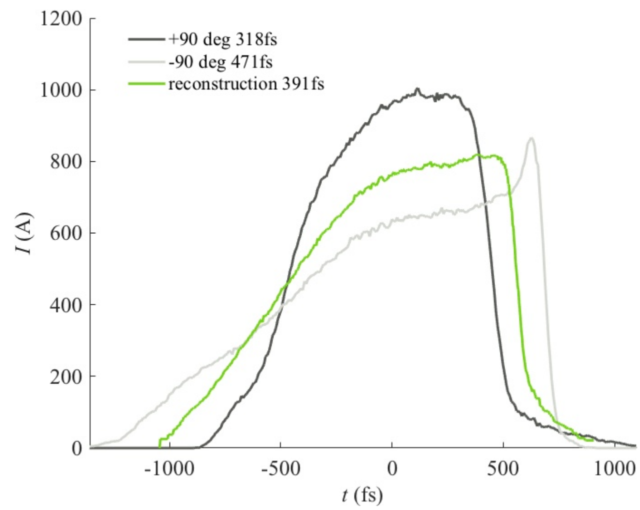

Figure 3: Measurement result of the transverse deflecting structure LOLA with a bunch length of about 391 fs and a peak current of about 770 A.

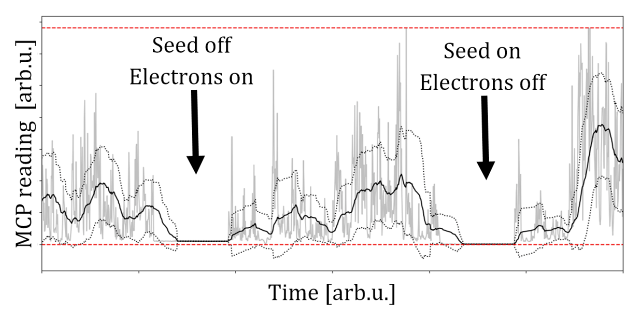

Figure 4: MCP signal. The larger signals come from the seeded radiation and show larger fluctuations. The first dip with visible radiation remaining shows the SASE radiation only, while the second dip shows that without the electron beam, the seed laser is not able to produce a signal exceeding the noise background of the MCP/ADC combo.

In parallel, the FLASH2 beam line was tuned for generation of SASE radiation.

RESULTS

Since the energy detector, a micro channel plate, is also sensitive to the seed laser and electromagnetic showers due to beam losses it is crucial to check that the signal observed is really generated by the seeding process. First, the seed laser is off, thus one would expect a lower, yet non-zero, photon pulse energy as the partially compressed electron bunch still generates SASE radiation. This is visible within Fig. 4 where the first dip is where the seed laser was switched off. Here, the SASE signal is clearly lower than the seeded one while still clearly exceeding zero. The second dip in the same

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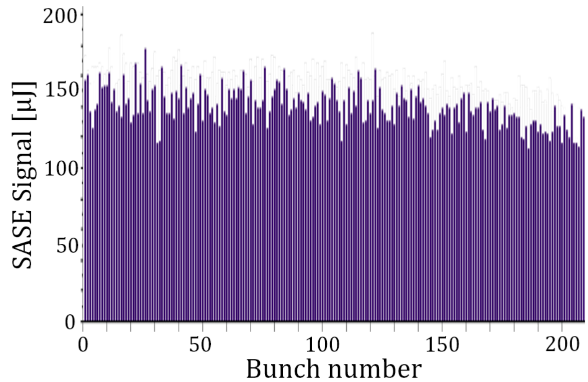

Figure 5: Screenshot of the control system panel showing the SASE pulse energy measured by a gas detector monitor in FLASH2 for a bunch train consisting of 210 bunches. The image shows the electron signal of the GMD, thus the per-pulse produced FEL photon pulse energy.

figure shows the MCP reading when the seed laser is on, but no electron beam present. Here, the signal completely vanishes into the noise floor of the used MCP/ADC combo. With those two measurements one can conclude that the radiation measured on the MCP is requiring the electron beam and laser seed pulse alike, thus it is indeed a seeded signal.

At the same time these experiments were performed the SASE signal at the FLASH2 beamline was exceeding 150 µJ for each of the 210 electron bunches sent to the beam line (see Fig. 5). Again, it is very important to note that the seeded signal was observed at the exact same time when FLASH2 was lasing with this performance.

SUMMARY AND OUTLOOK

We have shown that the setup of a seeded FEL at FLASH1 and a SASE FEL at FLASH2 are not mutually excluding each other. Decent SASE performance can be achieved at the same time as a seeded FEL is operated. This is an important result for FLASH, as it aims to be the first user facility at MHz repetition rate to use a SASE and a seeded FEL beam line simultaneously.

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