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STATUS OF THE SUPERCONDUCTING SOFT X-RAY FREE-ELECTRON LASER USER FACILITY FLASH AT DESY

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Abstract

FLASH, the free electron laser user facility at DESY (Hamburg, Germany), delivers high brilliance XUV and soft X-ray FEL radiation to photon experiments with different parameters at two undulator beamlines simultaneously. FLASH's superconducting linac can produce bunch trains of up to 800 bunches within a 0.8 ms RF flat top at a repetition rate of 10 Hz. In standard operation during 2018, FLASH supplied up to 500 bunches in two bunch trains with independent fill patterns and compression schemes to each of the two beamlines. In 2018 first successful plasma accelerating experiments could be reported by the FLASH-Forward plasma wakefield acceleration experiment situated in a third beamline. We report on the highlights of FLASH operation in 2018/2019.

FLASH FACILITY

The free-electron laser user facility FLASH [1–3] provides XUV to soft X-ray radiation pulses, based on the self-amplified spontaneous emission (SASE), at wavelengths down to 4 nm simultaneously in two undulator beamlines FLASH1 and FLASH2. The two FLASH undulator-beamlines are driven by a common accelerator consisting of a laser driven radio-frequency (RF) gun with a Cs_2Te photocathode, seven superconducting accelerating modules, a third-harmonic accelerating module, and two bunch compressors. An electron beam energy of up to 1.25 GeV can be reached. The superconducting technology allows the acceleration of electron bunch trains of several hundred bunches with a spacing of a microsecond or more and a repetition rate of 10 Hz. A fast kicker-septum system distributes one part of the bunch train to FLASH1 and the other part to FLASH2 keeping the full 10 Hz repetition rate for both beamlines. With this, two experiments can run at the same time. The bunch pattern and compression scheme can be chosen almost independently for each beamline allowing to tune the SASE properties specifically for each of the two experiments.

Figure 1 shows a schematic layout of the FLASH facility with its common accelerator and the two undulator beamlines with their own experimental halls. In addition, a third electron beamline FLASH3 hosts a pioneering beam driven plasma-wakefield acceleration experiment, FLASH-Forward [4]. The FLASH1 beamline has six fixed-gap undulators, with a length of 4.5 m each. The SASE wavelength of FLASH1 is determined by the electron beam energy. FLASH2 consists of twelve variable-gap undulators with a length of 2.5 m each, which allows choosing the wavelength to a certain extent independently from FLASH1 by varying the gap width of the undulators. The range is from one to three times the FLASH1 wavelength.

An overview of the photon science at FLASH and the evolution of the FLASH facility over the years can be found in [5, 6]. For more details of the facility and its parameters we refer to [2, 3, 7].

OPERATION

In 2018, FLASH1 was operated a total of 7103 hours, of which 59% (4189 h) was devoted to FEL user operation, 30% for studies and user preparation, and 11% for general accelerator R&D. During user operation, SASE radiation was delivered to the experiments 82% of the time, set-up and tuning for user requirements took 15%, and downtime due to technical failures was 3%. FLASH2 was operated 6831 hours, of which 33% (2269 h) was FEL user operation.

The year 2018 was divided into two user periods (period 11 and 12). FLASH served beam time for 38 experiments; many wavelengths in the XUV and soft X-ray range from 52 down to 4.4 nm have been realized. In 2018, two photon beamlines have been completed in the FLASH2 Kai Siegbahn experimental hall. This led to an increase of scheduled user experiments in FLASH2, a plus of 50% compared to 2017.

PHOTOINJECTOR

The photoinjector operates three different lasers which run simultaneously on all beamlines. Using different lasers with different pulse length, transverse shape, and pulse energy gives us the possibility to adapt the electron beam properties already at the source to the requirements of the parallel running user experiments.

The RF gun of the FLASH phototinjector is in operation since August 2013. In summer 2018, its RF window developed a small vacuum leak in the order of $7 \cdot 10^{-8}$ mbar l/s and has been replaced. The window was in operation for two years.

The photocathode was in continuous operation at FLASH for four years. This is by far the longest time such a cathode has been operated continuously anywhere in the world. It is a thin film of caesium tellurite (Cs_2Te) with a diameter of 5 mm on a molybdenum plug [8]. It has finally been exchanged in December 2018. The total charge extracted from this cathode is 25 C. The quantum efficiency of the photocathode was remarkable stable over the years with an average of 9%. Degradation was observed a few times when vacuum leaks occurred in the close-by beam-

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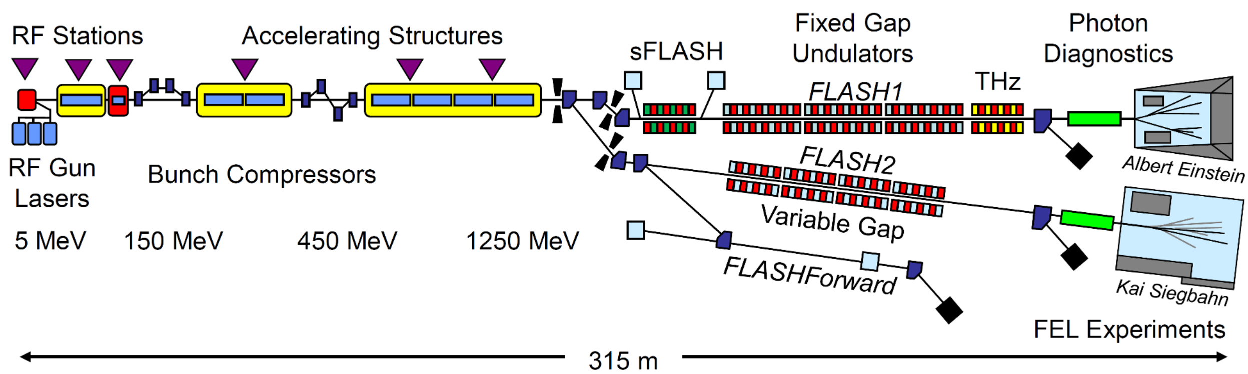

Figure 1: Layout of the FLASH facility (not to scale).

line or at the RF window of the RF gun. The final quantum efficiency was with 4.7 ± 0.7% still good. The argument to change the cathode was a growing inhomogeneity at its center. The cathodes for FLASH, PITZ, and the European XFEL are produced at LASA, Milano, Italy and at DESY.

HIGHLIGHTS

The new FLASH2 pump-probe laser system [9] was commissioned in September 2018 with a successful pilot experiment. Meanwhile further experiments have been carried out using the new pump-probe laser system at FLASH2.

Most experiments at FLASH1 are indeed pump-probe experiments with optical lasers, for example 58% in period 11, 71% in period 12. Therefore, the availability of the new pump-probe laser system at FLASH2 significantly increases the number of possible experiments.

One important feature of FLASH2 is the variability of the undulators gaps. We have already shown, that varying the SASE wavelength by changing the gap is possible within a few minutes per wavelengths step. A change of the undulator gap however requires adaption of optics, correction magnets, and phase shifters. These features have been automatized such that users can control the wavelengths by themselves. Even more, wavelength change can now be incorporated into automated scanning scripts.

The studies of testing novel lasing schemes with variable gap undulators have been continued. Recently, a scheme to generate two colors using alternating undulator gaps has been demonstrated. Even and odd undulators are tuned to different wavelengths. This scheme allows a free choice of two colors.

Furthermore, the harmonic lasing self-seeding scheme (HLSS) [10] has been successfully used for a user experiment. Both SASE and HLSS have been used for the same experiment, keeping the same pulse energy, pulse duration, and source position but improving the coherence time with the HLSS scheme.

A novel fast line detector for intra-train spectrum measurements named KALYPSO [11] has been installed in the FLASH1 photon beamline. It allows an online single shot measurement of the SASE wavelength spectrum along the whole bunch train for several hundreds of bunches. This is a great help to tune and monitor the spectral properties of SASE pulses along bunch trains in real time. This significantly improves the performance of experiments using the plane grating spectrometer at FLASH1 and is now a standard tool for setting up and running these kind of experiments.

sFLASH, the seeding experiment at FLASH1, established high-gain harmonic generation seeding (HGHG) [12]. To reach seeding at shorter wavelengths the next step will be a proof-of-principle experiment showing, that the echo-enabled seeding scheme (EEHG) is also possible at FLASH.

The installation and commissioning of the FLASHForward [13] beamline is ongoing. Two major components, the beam scraper to generate witness and driver bunches and the central plasma chamber housing the plasma source, have been installed and brought into operation. After a first attempt to interact beam with plasma in June 2018, a field strength of >10 GV/m was observed, with externally injected bunches subsequently accelerated with >3 GV/m gradients. The first experiment performed at FLASHForward – in which an arbitrarily chirped FLASH bunch was dechirped in plasma [14] – was successfully conducted in July 2018, fully compensating a linear chirp of 60.5 MeV/mm by adjusting the arrival time of the electron bunch with respect to the plasma discharge time. The applied dechirping strength of 1.8 GeV/mm/m is two orders of magnitude greater than competing state-of-the-art techniques. Experimentation has and will continue throughout the coming years with many more exciting results expected.

The beam arrival time measurements are of uttermost importance for time critical experiments on the femto second scale. The FLASH beam arrival time monitors (BAM) pick a signal form the electron beam and cross-correlate it with external ultra-stable lasers used to synchronize the beam with the photoinjector and the pump-probe lasers. Since the system installed a couple of years ago was not sensitive enough to small bunch charges below 200 pC, new pick-ups have been designed and installed in summer 2018. These new pickups together with an improved optical master laser reference system now provide an improved resolution es-

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pecially for small bunch charges (around 20 pC) used for short pulse operation (<30 fs). In first successful tests, together with BACCA [15] in a fast intra-train feedback, the arrival time stability of the electron beam has further improved from the present 20 fs level to below 5 fs. BACCA is a newly installed warm S-band RF cavity just before the first bunch compressor operated at about 1 kW RF power. The cavity has a significantly higher bandwidth than the superconducting RF cavities of the FLASH accelerating modules and thus allows a faster feedback on the remaining energy fluctuations of the electron bunches along the bunch train.

OUTLOOK

In order to provide photon pulse duration diagnostics for user experiments at FLASH2, a permanent set-up based on THz streaking is under commissioning. To measure the electron bunch longitudinal phase space in the FLASH2 beamline, a new transversely deflecting X-band RF cavity with variable polarization called PolariX-TDS is under construction [16]. A prototype will be installed into the FLASHForward beamline in summer 2019 followed by two cavities for FLASH2 in summer 2020.

A third bunch compressor chicane will be installed in summer 2019 downstream the extraction beamline (from the FLASH linac to FLASH2). The aim is to reduce the peak current of the electron bunches in the extraction arcs which will significantly improve the beam quality [17].

Further refurbishment and upgrade plans of the whole FLASH facility are discussed in [18]. A concept for upgrades of the FLASH2 undulator beamline is discussed in [19].

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