FIRST SIMULTANEOUS OPERATION OF TWO SASE BEAMLINES IN FLASH

M. Scholz*, B. Faatz, S. Schreiber, J. Zemella, DESY, Hamburg, Germany

Abstract

FLASH2, the second undulator beamline of the FLASH FEL user facility at DESY (Hamburg, Germany) is under commissioning. Its first lasing was achieved in August 2014. FLASH is the first soft X-ray FEL operating two undulator beamlines simultaneously. Both undulator beamlines are driven by a common superconducting linear accelerator with a beam energy of up to 1.25 GeV. Fast kickers and a septum are installed to distribute one part of the electron bunch train to FLASH1 and the other part to FLASH2 with full repetition rate. The commissioning of FLASH2 takes place primarily in parallel to FLASH1 user operation. Various beam optics measurements have been carried out in order to ensure the required electron beam quality for efficient SASE generation. This paper reports the status of the FLASH2 commissioning.

INTRODUCTION

FLASH [1–3], the free-electron laser (FEL) at DESY, Hamburg, Germany, delivers high brilliance XUV and soft X-ray FEL radiation for photon experiments. The superconducting accelerator technology used in the FLASH linac allows RF pulse lengths up to 800 µs. That makes it possible to accelerate electron bunch bursts with several hundred bunches. The bursts come with a repetition rate of 10 Hz and the maximum repetition rate of the single bunches within the bursts is 1 MHz. The bursts can be divided into parts, which can then be assigned to different undulator beamlines.

During a shutdown in 2013, FLASH was upgraded with a second undulator beamline [4, 5]. Fast kickers and a DC Lambertson-Septum are installed downstream the FLASH linac allowing to distribute the electron beam either to FLASH1 or to the extraction arc leading to FLASH2. Figure 1 shows the first extraction components. The schematic layout of the FLASH facility is shown in Fig. 2.

Due to fixed gap undulators, the photon wavelength delivered by FLASH1 determines the electron beam energy. FLASH2 is equipped with a variable gap undulator thus the photon energy can also be changed, within limits, by varying the undulator gap size. First lasing in the new undulator beamline was achieved on August 20, 2014 [6] and several different machine setups have been tested since then. The commissioning of FLASH2 takes place mostly in parallel to FLASH1 user operation. In this paper, we describe the parallel operation of the two undulator beamlines as well as the commissioning status of FLASH2.

* matthias.scholz@desy.de

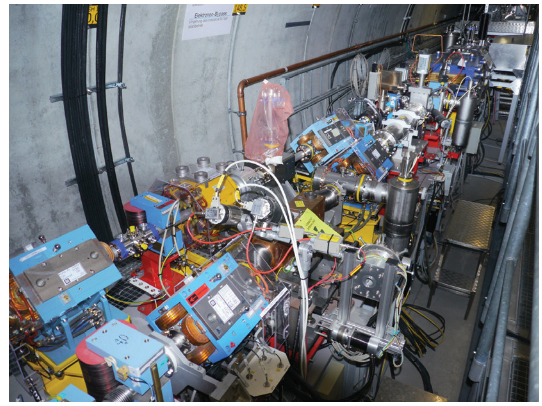

Figure 1: The first elements of the extraction arc leading the electrons to the new beamline FLASH2 are depicted on the left hand side. The beamline on the right hand side is FLASH1.

RF CONTROL FOR SIMULTANEOUS OPERATION

The RF-pulse is shared between the electron bunch trains for FLASH1 and FLASH2. For a 800 µs long FR-pulse, the total maximum number of bunches, with a bunch repetition rate of 1 MHz, is 800. The bunch pattern (number of bunches and intratrain repetition rate) and bunch charge can be different for FLASH1 and FLASH2. This is realized by using two independent injector lasers in parallel.

Between the two bunch trains there is a gap of about 50 µs, which is required to rise the current of the FLASH2 extraction kickers and to establish a current flattop that ensures the same kick for all bunches in the burst. The kicked bunches are deflected by a septum magnet to the FLASH2 beamline. Other bunches travel straight through the septum to FLASH1.

The gap between the bunch trains can also be used to change the RF pulse amplitudes and phases (both within limits) in the accelerating modules in order to adjust the beam energy and the compression for both beamlines separately. Figure 3 shows the RF steps of two coupled modules (ACC4 and ACC5) during parallel operation of FLASH1 and FLASH2. The picture shown is taken after a FLASH2 dispersion measurement during which the beam energy in FLASH2 was changed by ± 3 MeV. This was achieved by changing the FLASH2 RF amplitude in the modules accordingly. FLASH1 delivered FEL beam for a user experiment during this measurement thus its RF settings must stay unchanged. In addition to the different amplitudes, the phases of the modules were set to 1.5 degree off-crest for FLASH1 while the FLASH2 bunches were accelerated on-crest.

ISBN 978-3-95450-134-2

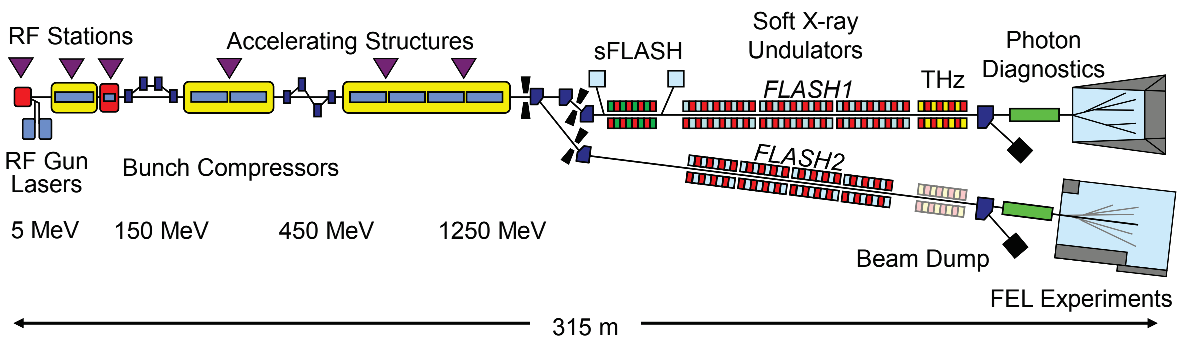

Figure 2: Schematic layout of the FLASH facility including the superconducting linac, the bunch compressors and the undulator beamlines FLASH1 and FLASH2. The location of a seeding experiment sFLASH is indicated.

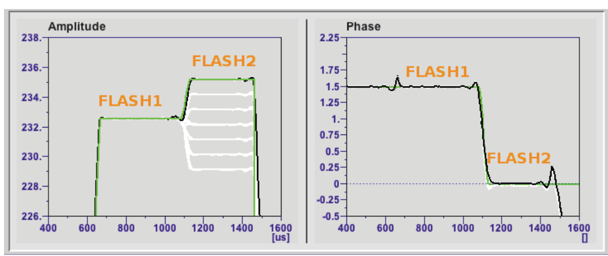

Figure 3: RF amplitude (left) and phase (right) of accelerating modules. The RF pulse length (800 µs) is split in two parts, one for each beamline. Both, the amplitude and the phase have different settings for FLASH1 and FLASH2. The units of the horiztontal axes are micro seconds. The untit for the RF amplitude is energy gain in MeV and the unit for the RF phase its degree.

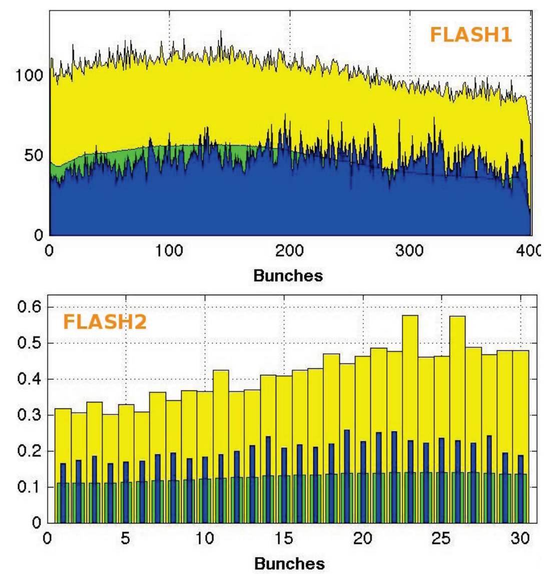

Figure 4: SASE pulse energy per bunch (in a.u.) for 400 bunches in FLASH1 (upper plot) and for 30 bunches in FLASH2 (also in a.u.). Blue: Actual value, Green: Average, Yellow: Maximum.

A slow bunch compression feedback uses the RF steps to keep the compression of the bunches constant over time for both beamline separately.

PARALLEL OPERATION OF TWO UNDULATOR BEAMLINES

The first electron beam in the FLASH2 extraction arc could be realized on March 4, 2014 and the first electrons in the FLASH2 dump could be achieved on May 23, 2014. Most of the FLASH2 commissioning has taken place in parallel to FLASH1 user operation. Dedicated beam time for FLASH2 has been restricted to a few days per month. During the first tests with electron beam, the gap of the FLASH2 undulators was open in order to avoid radiation damage of the permanent magnets.

First SASE operation in FLASH2 was achieved August 20, 2014 [6] during FLASH1 operation with 250 bunches per burst delivering photons at a wavelength of 13.5 nm. The FLASH2 undulator was closed to 9.5 mm which led, with a beam energy of 680 MeV, to a photon wavelength of 40 nm. This was the first time that two soft X-ray FEL beamlines driven by the same linac were operated in parallel.

So far, the maximum number of bunches per burst during a parallel SASE operation of both beamlines has been 400 bunches in FLASH1 and 30 bunches in FLASH2, both with a bunch repetition rate of 1 MHz. Figure 4 shows the SASE pulse energy, measured by the MCP (Microchannel plate [7]) detectors, along the bunch trains in FLASH1 and FLASH2.

The plots presented in Figures 5 and 6 give an overview of parallel SASE operations of FLASH1 and FLASH2. The first plot covers the period from August, 2014 to August, 2015 and the second plot covers the period from June 2015 to August 2015.

In Fig. 5 photon wavelengths generated by FLASH1 and FLASH2 during parallel SASE operation are depicted as a function of the electron beam energy. Due to the fixed gap undulator, the wavelength of FLASH1 is coupled to the electron beam energy. However, FLASH2 can produce different wavelength at a fixed electron beam energy (within limits) by adjusting the undulator gap size. Already in the beginning of September 2014, several wavelengths below 40 nm

ISBN 978-3-95450-134-2

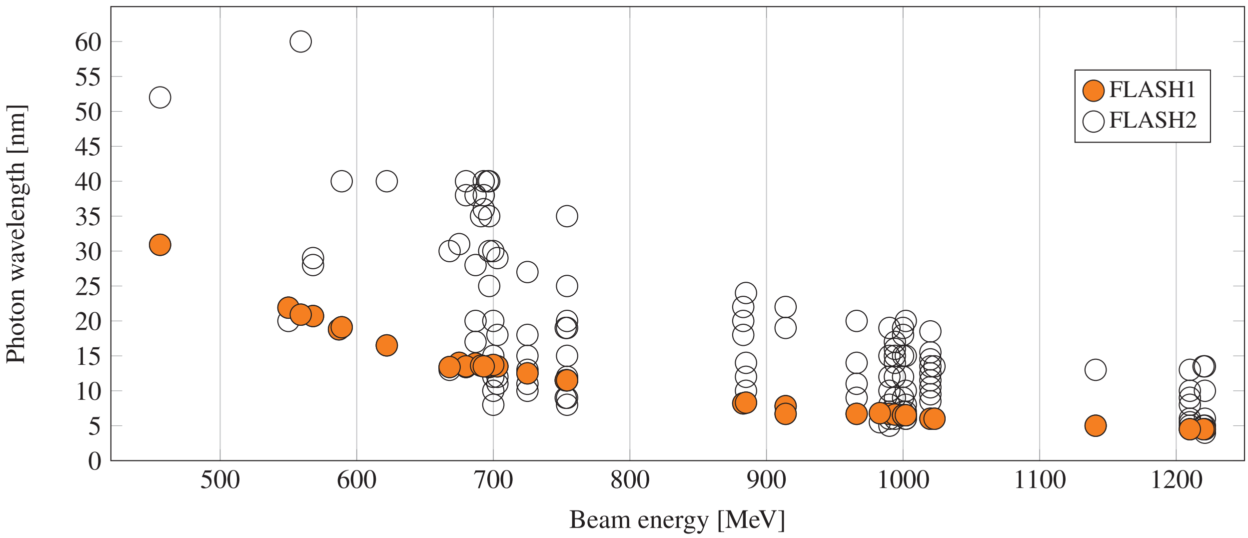

Figure 5: Photon wavelengths achieved in the FLASH1 and FLASH2 beamlines during parallel SASE operation in the period from August 2014 to August 2015. The photon wavelength in FLASH1 is determined — due to the fixed gap undulator — by the electron beam energy. FLASH2 is equipped with a variable gap undulator and the wavelength can be varied at fixed electron beam energy by changing the gap size.

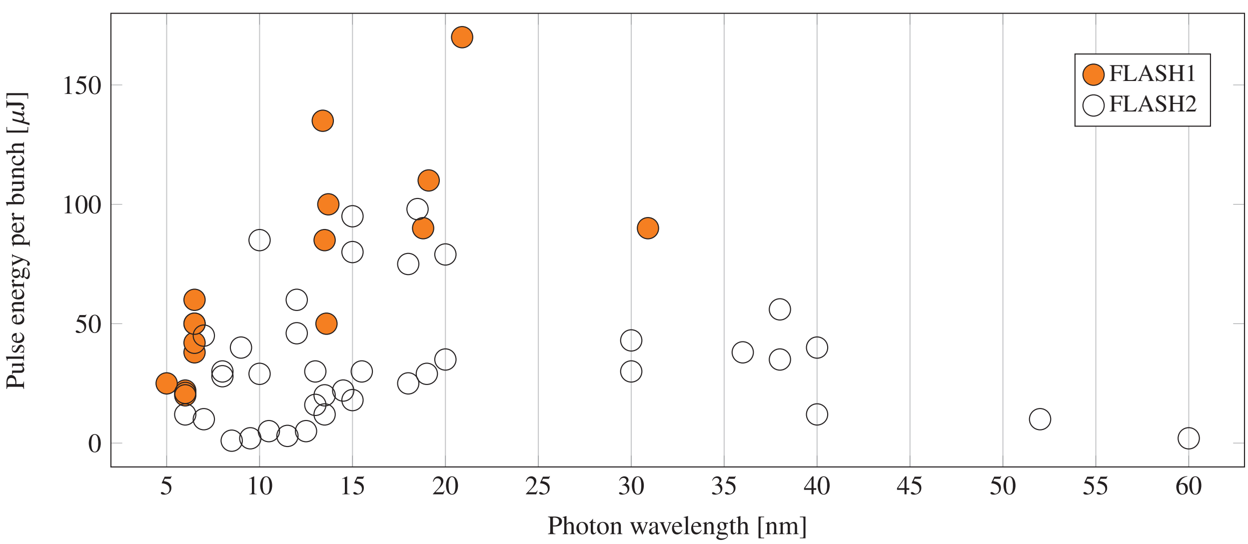

Figure 6: SASE pulse energies per bunch for photon wavelengths delivered by FLASH1 and FLASH2 achieved during parallel SASE operation in the period from June 2015 to August 2015.

were achieved as well. The shortest wavelength produced by FLASH2 so far, 4 nm, was obtained during an intense study week in January 2015. Due to installations of photon beam diagnostics in the FLASH2 tunnel, no parallel SASE operation was possible from mid January 2015 to June 2015. After that, further successful runs were carried out in summer 2015. The maximum photon wavelength at FLASH2, 60 nm, was achieved in June 2015.

The GMD detector, to measure the absolutely calibrated photon pulse energy, has been available at FLASH2 since June 2015. Therefore the data shown in Fig. 6 covers only the period from June to August 2015. The presented plot shows the pulse energy in both beamlines during parallel SASE operation for different photon wavelengths. Although FLASH2 has not yet reached the maximum photon energies of FLASH1, the achieved pulse energy of about 100 μJ at different wavelengths between 10 nm and 20 nm is promising.

For the long wavelengths, the pulse energies reached so far was rather small. The main reason for this is that for any given energy, emphasis has been on optimizing the FEL for shorter wavelengths, which is considered to be the more demanding challenge.

FLASH2 SASE commissioning continues during the next months.

ISBN 978-3-95450-134-2

SUMMARY AND OUTLOOK

We have had a very successful year with great advances in the commissioning of the new undulator beamline at FLASH2. The simultaneous SASE operation of FLASH1 and FLASH2 emphasizes the unique status of FLASH among the free-electron lasers.

The maximum SASE pulse energy of FLASH2 is still below the energy of the SASE pulses at FLASH1 but we are optimistic that FLASH2 can achieve similar level in the future. The minimum wavelength in FLASH2 reached so far with saturated photon beam is 5 nm. Simulations show that for nominal parameters, 4 nm can be reached at 1.25 MeV, and we are confident that we can reach also shorter wavelengths in the near future. Many tools and diagnostic devices have been developed or adapted from FLASH1 to the new beamline, and further tools are under commissioning. First photon experiments are expected 2016.

ACKNOWLEDGMENT

We like to thank all colleagues who have been involved in the FLASH II project and participated in the commissioning of the new FLASH2 undulator beamline.

REFERENCES

[1] W. Ackermann et al., *"Operation of a free-electron laser from the extreme ultraviolet to the water window"*, Nature Photonics 1, 336 (2007).

[2] K. Tiedtke et al., *"The soft x-ray free-electron laser FLASH at DESY: beamlines, diagnostics and end-stations"*, New J. Phys. 11, 023029 (2009).

[3] K. Honkavaara et al., *"Status of the soft x-ray user facility FLASH"*, presented at FEL'15, Daejeon, Korea, Aug 2015, MOP014, these proceedings.

[4] M. Scholz, *"Design of the Extraction Arc for the 2^{nd} Beam Line of the Free-Elelctron Laser FLASH"*, DESY-Thesis-2014-002.

[5] M. Scholz et al., *"Extraction Arc for FLASH II"*, THP073, Proceedings of FEL2012, Nara, Japan.

[6] S. Schreiber, B. Faatz, *"First Lasing at FLASH2"*, MOA03 Proceedings of FEL2014, Basel, Switzerland.

[7] E. Syresin et al., *"Radiation detectors based on microchannel plates for free-electron lasers"*, `DOI:10.1134/S1547477114060144`.

ISBN 978-3-95450-134-2