

STATUS OF THE SOFT X-RAY FREE ELECTRON LASER FLASH

Mathias Vogt, Bart Faatz, Josef Feldhaus, Katja Honkavaara, Siegfried Schreiber, Rolf Treusch, DESY, Hamburg, Germany

Abstract

The superconducting free-electron laser FLASH at DESY routinely produces up to several thousand photon pulses per second with wavelengths in the soft X-ray and XUV regime and with energies up to 0.5 mJ per pulse. In 2014 the assembly of a second undulator beamline, FLASH2, was finished. Recommissioning of the FLASH linac and the original FLASH1 beamline was finished already end of 2013 and the commissioning of FLASH2 started in February 2014. Only a few weeks have been reserved for dedicated set up of FLASH2, and most of its commissioning has been performed parasitically during the FLASH1 user run. The first beam was extracted through the septum to the FLASH2 beamline on March 4th, 2014, and the first lasing of FLASH2 at a wavelength of about 40 nm was achieved on August 20th, while FLASH1 was lasing simultaneously with 250 bunches at 13.5 nm. We summarize here the status of the FLASH2 commissioning and the FLASH1 operation during its 5th user period.

INTRODUCTION

The soft X-ray SASE FEL FLASH [1–4] at DESY in Hamburg, Germany is driven by a normal conducting RF photo cathode gun (RF-gun) and a superconducting linac consisting of seven 1.3 GHz accelerating modules with eight TESLA-type 9-cell cavities each. The superconducting modules are capable of producing 800 μ s long accelerating flat tops every 100 ms. The UV injector lasers [5] and the Cs₂Te photo cathode [6] are in their standard set up capable of producing 800 μ s long pulse bursts of 800 pulses (1 MHz) at 10 Hz. FLASH is therefore ideal for an upgrade to share the long bunch trains between multiple beamlines and thus serve several FEL user experiments simultaneously at 10 Hz burst repetition rate. The accessible wavelength range produced by the FLASH1 undulator is 4.2 nm up to 52 nm. Every year FLASH attracts more users than could possibly be served with only one undulator beam line. A selection of publications based on science at FLASH can be found in [7]. In 2012 and 2013 a new second beam line, FLASH2 [8, 9], was built. Its commissioning started in February 2014. A detailed overview over the history of the FLASH facility can be found in [1]. A schematic layout of the facility with its common parts, i.e. RF-gun, first acceleration stages, two magnetic chicanes (“bunch compressors”), 3rd harmonic compression linearization and the main linac (four acceleration modules), the extraction switch yard and the two beam lines FLASH1 and FLASH2 is shown in Fig. 1. A more detailed description of the layout and a table of typical run parameters can be found in [2].

FLASH1 USER OPERATION AND HIGHLIGHTS OF STUDIES

In 2014 about 4200 h (\approx 50% of the total year) were dedicated to user operation, roughly 3400 h (\approx 40%) for machine development, photon beamline commissioning and general accelerator studies, and approximately 1200 h (\approx 10%) for shutdown maintenance and commissioning. The overall down time over the ca. 7800 h of scheduled operation was \approx 4.5%. Routinely, high SASE energies with up to several hundreds of μ J or alternatively short photon pulses ($<$ 50 fs) were achieved for 10 to 4000 pulses per second. In April 2014 the RF coupler window of the RF-gun was changed because of a developing vacuum leak. The unavoidable re-conditioning of the window affected the FEL operation in so far that the initial RF pulse duration did only allow for about 30 bunches per train over the first three weeks and that it took another month to reach 400 bunches [2]. Since June 2014 however, the RF-gun is running very stable with a gradient at the cathode of about 53 MeV/m (corresponds to about 4.8 MW of forward power) and 470 μ s flat top.

Using a new third injector laser, capable of producing pulses of only about 1 ps duration, lasing was achieved in single spike mode, i.e. with 3 to 5 fs long photon pulses [10]. The group performing seeding experiments in the FLASH1 e^- beamline has recently achieved HGHG seeding around 38 nm with an energy contrast of about 1000 [11]. Although seeding experiments so far were all performed during dedicated studies, schemes for quasi-parasitic operation parallel to FLASH1 user operation are under preparation [12]. With the increased requirements on beam quality and reproducibility (e.g. for seeding and multi beamline operation) and given the fact that optics perturbations are known to exist in the FLASH injector, it became necessary to start a campaign on optics consolidation [13]. A progress report of the optics studies is given in [14]. Since autumn 2013 accelerator modules are regulated by a sophisticated MTCA.4 based LLRF system [15, 16]. The RF-gun was upgraded to the MTCA.4 in January 2015 [17, 18].

The 5th user period finished in the end of April 2015 and after a short shutdown in May the 6th user period will start in June 2015. The three week shutdown in May is dedicated to complete the radiation shielding in the area between the FLASH1 and FLASH2 tunnels, including survey and realignment of the undulator and photon beamlines.

FLASH2 COMMISSIONING & PARALLEL OPERATION OF TWO BEAMLINES

To preserve as much FLASH1 user time as possible, only very little dedicated FLASH2 commissioning time was allocated. First beam passed the septum on March 4th, 2014 and

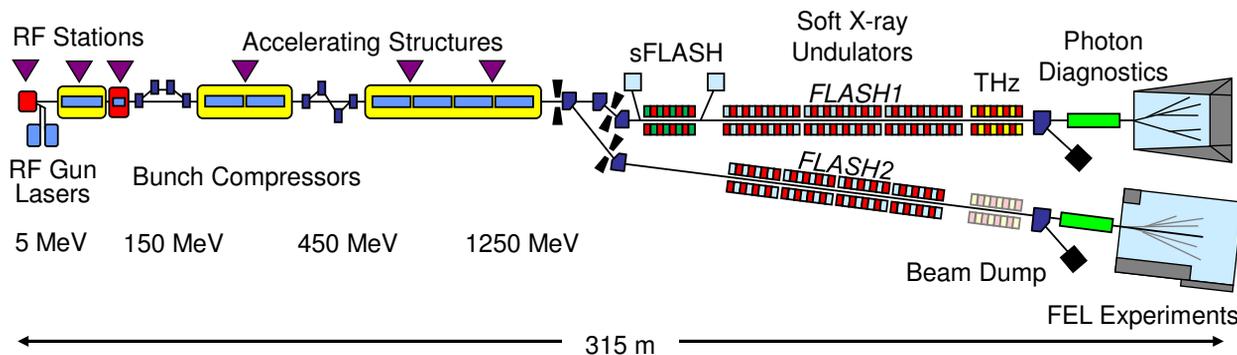


Figure 1: The FLASH facility with the injector, the main linac, and the two beam lines FLASH1 and FLASH2. (Not to scale.)

first beam was visible at the FLASH2 dump screen on May 23rd, 2014. During these first tests the FLASH2 variable gap undulators were all fully opened. Then the beam loss monitoring system, the BPM systems (low-charge button BPMs with in-house made electronics and XFEL-type cavity BPMs with electronics supplied by PSI), and the machine protection system had to be commissioned [19]. First lasing was achieved in FLASH2 on first attempt on August 20th at a FEL wavelength of 40 nm [3]. This was not only first SASE in FLASH2 but also the first time two FEL beamlines had been lasing in parallel at all [1, 3]. At the same time FLASH1 was operating with 250 bunches lasing at 13.5 nm.

The dispersion from the extraction arc was measured and first procedures for closing it in various machine state were tested successfully [20]. Since then, lasing at FLASH2 was established at various wavelengths. Fig. 2 shows the transverse beam spot of the FLASH2 FEL beam on a Ce-YAG screen in the photon beam line for 4 different wavelengths.

FLASH2 had a shutdown from mid January to mid April 2015 to install the final version of the photon beam line with the full diagnostics and connect it to the new experimental hall. The electron beam operation was re-established for FLASH2 in mid April 2015 and SASE operation will continue in June in parallel to FLASH1 operation.

One of the major challenges is the stable day-by-day simultaneous operation of two FEL beamlines.

Control over the e^- -beam optics is crucial for reproducible FEL operation. Minimizing the emittance degradation due to coherent synchrotron radiation in the extraction septum adds another critical constraint to the optics, namely the existence of a beam waist with optimized parameters at the septum [21]. It is desirable to have an online tool for monitoring of the optics quality. Some ideas for such an online tool are discussed in [22].

The switch yard distributes the beam into the dispersive E -collimation arcs of FLASH1 and FLASH2. The orbit in this section is critical for the FEL performance of both beamlines. At the same time the orbit must be optimized to allow loss free transmission into FLASH1 and FLASH2.

Serving two (or more) beamlines complexifies the timing and control system. Variable bunch patterns for FLASH1

and FLASH2 need not only to be generated at the associated injector laser but need to be followed through different parts of the machine with all its consequences regarding “reference bunches” for diagnostics and for the machine protection system. Most control servers are now able to consistently handle the two “virtual accelerators” FLASH1* & FLASH2* which start at the associated injector laser, share the section from RF-gun to switch yard, and end at their specific beam dump.

For versatile operation with two beamlines it is favorable to provide independent charge states and compression schemes for each beamline. At FLASH this is achieved by 1st the two independent injector lasers capable of producing independent bunch patterns and charge states and 2nd by the ability of the RF systems to provide independent (within bounds) RF flat tops for the two bunch trains. The split RF flat tops, separated by a transient time of typically 30–80 μ s can have different phases to provide bunches with different E -chirp and different amplitudes to compensate for the changed E -gain due to the changed phase.

With the two beamlines FLASH now has increased complexity with more equipments and procedures and parameters to control. By the common part of the accelerator, the operation of both beamlines is strongly coupled. As an example, the steerers in the two beamlines at the switch yard are so close to the other beamline that they couple into the other beam line with up to 10% kick strength. An active compensation scheme using coupled 3-bumps is currently being developed [23]. FLASH will now have regularly two operators to tune and control the two beamlines but they cannot act independently. New procedures for setting up and tuning the machine consistently for both beamlines are being developed.

It is planned to have a pilot user experiment in FLASH2 at the end of the year. Regular user operation in FLASH2 is scheduled for 2016.

ACKNOWLEDGMENTS

We would like to thank all the colleagues at DESY and from the collaborating institutes for their continuous dedica-

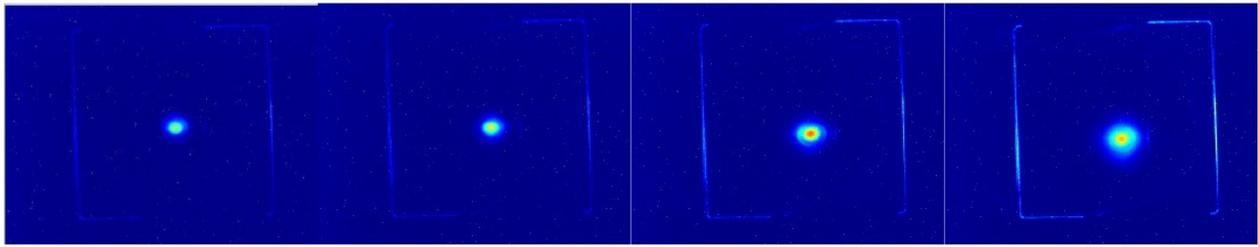


Figure 2: FLASH2: FEL beam spot on Ce-YAG screen for various wavelengths obtained by changing the undulator gap within about 30 min. for all wavelengths. From left to right: 6.0 nm, 8.5 nm, 11.0 nm, 13.5 nm.

tion in operation, maintenance and upgrade of FLASH and in particular during the construction and commissioning of the FLASH2 beam line.

REFERENCES

- [1] K. Honkavaara et al., “FLASH: First Soft X-Ray FEL Operating Two Undulator Beamlines Simultaneously”, WEB05, textitProc. FEL’14, Basel, Switzerland (2014).
- [2] M. Vogt et al., “Status of the Free Electron Laser User FLASH”, TUOCA02, textitProc. IPAC’14, Dresden, Germany (2014).
- [3] S. Schreiber, B. Faatz, “First Lasing at FLASH2”, MOA03, textitProc. FEL’14, Basel, Switzerland (2014).
- [4] K. Honkavaara et al., “Status of the FLASH Facility”, WEP026, textitProc. FEL’13, NYC, NY, USA (2013).
- [5] S. Schreiber et al., “Operation of the FLASH Photoinjector Lasersystem”, THPA18, textitProc. FEL’11, Shanghai, PRChina (2011).
- [6] S. Lederer et al., “Photocathodes at FLASH”, THPA19, textitProc. FEL’11, Shanghai, PRChina (2011).
- [7] <http://photon-science.desy.de/facilities/flash/publications/>.
- [8] K. Honkavaara et al., “Status of the FLASH II Project”, WEPD07, textitProc. FEL’12, Nara, Japan (2012).
- [9] B. Faatz, “Status of the FLASH II Project”, TUPA22, textitProc. FEL’11, Shanghai, PRChina (2011).
- [10] J. Roensch-Schulenburg et al., “Operation of FLASH with Short SASE Radiation Pulses”, FEL’14, Basel, Switzerland (2014).
- [11] J. Bödeewadt et al., “Recent results from FEL seeding at FLASH”, TUBC3, *These Proceedings*, IPAC’15, Richmond, VA, USA (2015).
- [12] Ph. Amstutz et al., “Optics Compensation for Variable-Gap Undulator Systems at FLASH”, TUPWA038, *These Proceedings*, IPAC’15, Richmond, VA, USA (2015).
- [13] J. Zemella et al., “Measurements of the Optical Functions at FLASH”, TUPRO050, textitProc. IPAC’14, Dresden, Germany (2014).
- [14] J. Zemella et al., “Progress In Optics Studies at FLASH”, TUPWA033, *These Proceedings*, IPAC’15, Richmond, VA, USA (2015).
- [15] M. Omet et al., “Operation Experiences with the MTCA.4-based Digital LLRF Control System at FLASH”, MOPHA029, *These Proceedings*, IPAC’15, Richmond, VA, USA (2015).
- [16] R. Rybaniec et al., “Microphonics Disturbances Prediction and Compensation in Pulsed Superconducting Accelerators”, WEPMN032, *These Proceedings*, IPAC’15, Richmond, VA, USA (2015).
- [17] M. Hoffmann et al., “Operation of Normal Conducting RF Guns with MTCA.4”, MOPHA028, *These Proceedings*, IPAC’15, Richmond, VA, USA (2015).
- [18] S. Pfeiffer et al., “Virtual Cavity Probe Generation using Calibrated Forward and Reflected Signals”, MOPWA040, *These Proceedings*, IPAC’15, Richmond, VA, USA (2015).
- [19] N. Baboi, D. Noelle, “Commissioning of the FLASH2 Electron Beam Diagnostics in Respect to its use at the European XFEL”, THIXB1, *Proceedings IBIC’14*, Monterey, CA, USA (2014).
- [20] M. Scholz et al., “Beam Optics Measurements at FLASH2”, MOPHA035, *These Proceedings*, IPAC’15, Richmond, VA, USA (2015).
- [21] M. Scholz, “Design of the Extraction Arc for the snd Beam Line of the Free-Electron Laser FLASH”, PhD thesis, Hamburg University, 2013.
- [22] F. Mayet et al., “Implementation of a Diagnostic Pulse for Beam Optics Stability Measurements at FLASH”, MOPHA031, *These Proceedings*, IPAC’15, Richmond, VA, USA (2015).
- [23] F. Müller, MSc Thesis, Hamburg University, in preparation.