STATUS OF THE FLASH FACILITY

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Abstract

The free-electron laser user facility FLASH at DESY (Hamburg, Germany) finished its 4^{th} user period in February 2013. In total 2715 hours of SASE radiation have been delivered to user experiments with photon wavelengths between 4.2 nm and 44 nm and up to 5000 photon pulses per second. After a shutdown to connect the second undulator line - FLASH2 - to the FLASH linac, and a following commissioning period, FLASH is scheduled to continue user operation late 2013. The year 2014 will be dedicated to the 5^{th} period of user experiments. The commissioning of FLASH2 will take place in 2014 in parallel to the FLASH1 operation.

INTRODUCTION

FLASH [1–4], the free-electron laser (FEL) user facility at DESY (Hamburg), delivers high brilliance XUV and soft X-ray FEL radiation for photon experiments. This paper summarizes the performance during the 4^{th} user period, reports the status of the FLASH II project, and outlines the midterm plans of the FLASH facility. Part of the material discussed here has already been presented in previous conferences [3–6].

FLASH FACILITY

The layout of the FLASH facility, including the second undulator line under construction, is shown in Fig. 1. Typical FLASH operating parameters can be found, for example, in [3].

A laser driven RF-gun produces trains with up to 800 high brightness electron bunches. The bunch train repetition rate is 10 Hz, and the typical bunch charge ranges from 80 pC to 1 nC. The photocathode laser system is based on an actively mode-locked pulse train oscillator with a linear chain of fully diode pumped Nd:YLF amplifiers [7, 8]. The cathode is exchangeable and consists of a thin film of Cs_2Te on a molybdenum plug [9].

During the last three years, severe problems have occurred related to the RF-gun and its RF-window [3] forcing us to exchange the window (autumn 2011) and the RF-gun (June 2012). During the 2013 shutdown a new RF-gun has been installed. In addition, new RF-gun design options and new RF window types are being tested.

The electron beam is accelerated up to 1.25 GeV by seven superconducting TESLA type accelerating modules. Each module has eight 9-cell niobium cavities operated at 1.3 GHz. In order to linearize the longitudinal phase space, four 3.9 GHz (third harmonics of 1.3 GHz) superconducting cavities are installed downstream the first module. Electron bunches are compressed by two magnetic chicane bunch compressors at beam energies of 150 MeV and 450 MeV to achieve the peak current required for the lasing process.

The RF-gun and the accelerating modules are regulated using a sophisticated FPGA based low level RF (LLRF) system [10, 11]. An upgrade to a μTCA based system is under way [12]. Other important developments are improvements on the synchronization and beam arrival time stabilization system including also beam based longitudinal RF-feedbacks [13–15]. A recent novelty is the possibility of on-line monitoring of the electron bunch length and shape using both a transverse deflecting cavity equipped with an off-axis screen and an in-vacuum polychromator measuring coherent radiation in THz and infrared range [16].

The electron beam passes through six 4.5 m long fixed gap (12 mm) undulator modules producing FEL radiation based on the SASE (Self Amplified Spontaneous Emission) process. Undulators consist of permanent NdFeB magnets, the undulator period is 27.3 mm, and the peak K-value 1.23. A planar electromagnetic undulator is installed downstream of the SASE undulators to produce - on request - THz radiation. The produced THz pulses are naturally synchronized with the SASE pulses. A seeding experiment sFLASH [17, 18] with four variable gap undulators is installed between the collimation section and the SASE undulators.

A sophisticated photon diagnostics section provides a possibility to measure and characterize the photon beam parameters. In the experimental hall, five photon beam lines are available for user experiments. Since FLASH has not yet permanent end-stations, each experiment has to provide and install its own measurement hardware. Photon diagnostics and photon beamlines are described in [2].

4^{TH} USER PERIOD

The 4^{th} FEL user period started end of March 2012. Unfortunately, after the two first user blocks, the break-down of the RF-gun forced us to stop the operation on June-7, 2012. As a consequence, one four-week user block was postponed from summer 2012 to early 2013. The RF-gun was successfully exchanged and the beam operation quickly re-established such that the next user block in Au-

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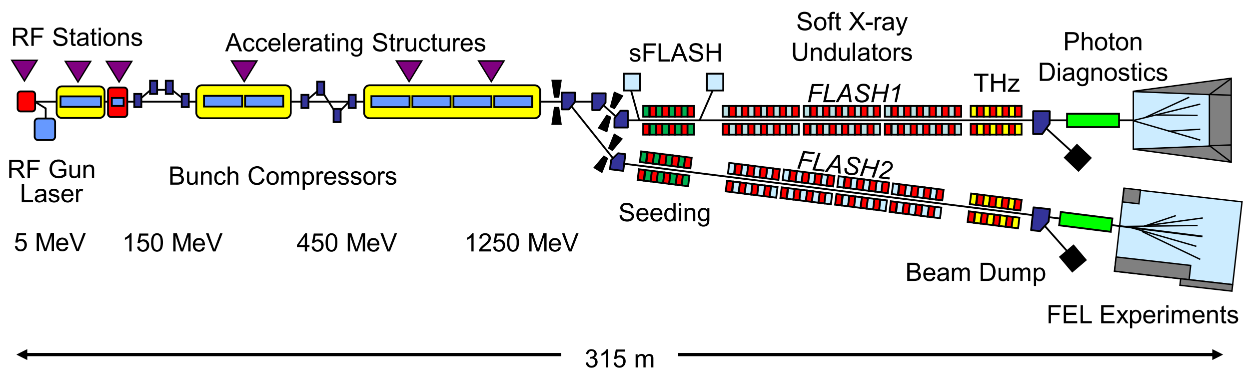

Figure 1: Layout of the FLASH facility with the new FLASH2 beamline under construction (not to scale).

gust 2012 could start as scheduled. The 4^{th} user period finished on Feb-17, 2013, followed by a shutdown required to connect the FLASH2 beamline to the FLASH linac.

The 4^{th} user period had 3528 hours scheduled for FEL users: 84% for user experiments, 7% for set-up the electron and photon beam, and 9% for contingency. Contingency was mainly used to compensate the loss of user beam time due to down- and tuning times. FEL radiation was delivered 75.2% of the time, tuning took 15.2%, and the total downtime was 9.6%. In total 2715 hours of FEL radiation were provided to experiments, corresponding to 92% of the time scheduled for them.

About half of the tuning has been standard tuning: change of the photon wavelength, increase of the photon pulse energy, correction of the photon beam pointing. The other half has been used to meet the special demands of the experiments, for example short (below 50 fs) photon pulses or long pulse trains (up to 500 pulses per train). The new operation mode including the generation of THz radiation required also dedicated tuning.

The downtime has increased by factor of two compared to the previous user period in 2010/11. The RF-gun breakdown caused about 20% of the total downtime. In addition, the RF-station (10 MW multibeam klystron, modulator, transformer, waveguides, circulators) powering the RF-gun has contributed significantly to the downtime. It is essential to mention that even a very short failure of the RF-gun or its RF-system causes a downtime between 20 and 60 minutes, the time needed to stabilize the RF-gun temperature. Improvements on the water system and LLRF controls are under way to speed up the start-up and stabilization process. An other notable downtime source has been problems with magnet power supplies, especially their controllers. In addition, faults on the water system (especially water flow meters of RF-stations) and on the photon beamline vacuum system, as well as beam losses causing radiation alarms, have caused significant amount of downtime. The downtime has been carefully analyzed, and the main sources identified. Countermeasures are under way to reduce the downtime back to the 4% level.

FEL Performance

During the 4^{th} user period, SASE FEL radiation has been delivered to user experiments with more than twenty different photon wavelengths between 4.2 and 44 nm. A stable operation with low charge electron bunches (60 – 80 pC), to provide short photon pulses (< 50 fs), has been successfully established for different wavelengths.

One of the highlights have been two experiments (in August and December 2012) carried out at wavelengths in the water window with photon pulse energies up to 100 μJ and 250 μJ, respectively.

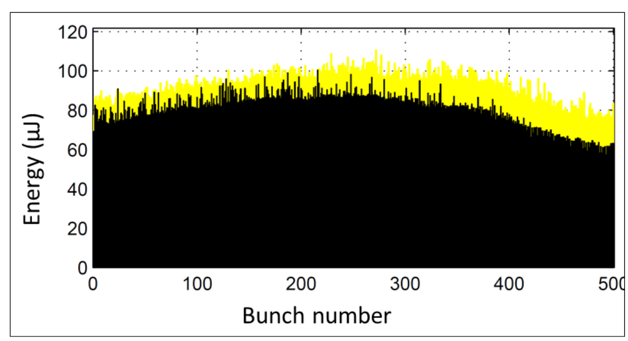

Figure 2: Train of 500 photon pulses. The pulse train repetition rate is 10 Hz, and photon wavelength 31 nm. Black: actual value, Yellow: maximum value.

Operation with long photon pulse trains is another realized milestone: 5000 photon pulses per second (500 pulses per train at repetition rate of 10 Hz, see Fig. 2) have been delivered at wavelength of 31 nm with an average photon pulse energy up to 80 μJ. A second example is an experiment carried out at 9.8 nm with 3000 pulses per second. This experiment, with photon pulse energies up to 200 μJ, resulted in a new record of the FLASH facility on the average FEL radiation power (600 mW).

FLASH is also an unique THz source [19]: 160 μm radiation with 600 pulses per second has been generated with up to 100 μJ pulse energy.

Stability is an important issue for many of the experi-

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ments. A sophisticated synchronization is used to provide, on request, the arrival time stabilization down to a few tens of fs.

FEL and Accelerator Studies

Since FLASH has not yet permanent end-stations, the photon experiments need a significant amount of the time to install and adjust their experimental set-up. In order to use effectively the exchange time between the experiments, study blocks (2-4 weeks), dedicated to further developments of FLASH and the European XFEL, have been scheduled in between the user blocks (4 weeks).

The study time is primarily allocated to improve the FLASH performance as an FEL user facility, for example to establish short pulse and long train operation, and to upgrade the electron and photon diagnostics as well as the LLRF and synchronization systems. Time is also reserved to prepare the facility for the demands of the experiments scheduled for the following user block.

In addition, specific time slots are devoted once or twice per year for general accelerator studies including, for example, developments for the International Linear Collider (ILC). An example of ILC related studies is the high beam loading experiment with up to 2400 electron bunches per train [11, 20].

The HHG (High Harmonics Generation) seeding experiment sFLASH [17, 18], and the project with a goal to generate low charge electron bunches (down to 20 pC) to produce single spike, longitudinally fully coherent photon pulses [21, 22] are other experiments carried out during the study blocks.

FLASH II PROJECT

The FLASH II project - upgrading the FLASH facility with a second undulator line and a second experimental hall - is under way. The FLASH linac will drive both undulator beamlines: FLASH1 with fixed gap undulators and FLASH2 with variable gap undulators. The wavelength range of FLASH2 is with 4 - 60 nm similar to FLASH1.

FLASH1 and FLASH2 share the same electron bunch train: part of the train is kicked to FLASH2 using a kicker-septum system, the other part serves FLASH1. Two photocathode lasers will be used to allow a different bunch charge and bunch pattern in the two beamlines. The operation with two lasers has already been successfully tested [23]. The LLRF system offers a certain flexibility to adjust the amplitude and phase of the accelerating modules within an RF-pulse independently for FLASH1 and FLASH2. However, since both parts of the bunch train are accelerated by the same linac, the acceptance of the beam optics must be taken into account, and thus FLASH1 and FLASH2 parameters cannot be completely independent from each other.

The FLASH2 operation starts with SASE only. A possible seeding scheme is under study, and the seeding hardware will be installed in a later stage.

The construction of the building hosting the new undulator line started in autumn 2011 and continued in several steps until early summer 2013. The infrastructure installation began in February 2013, and the electron beamline mounting in June 2013. The construction of the new experimental hall is on-going and will be completed early 2014.

The connection of the FLASH2 beamline to the FLASH linac required an opening of the wall between the FLASH1 and FLASH2 buildings. This construction work has been successfully carried out in spring 2013. In addition, 12 meters of FLASH1 beamline downstream of the last accelerator module have been modified to provide place for kickers, a septum magnet and other components needed to ensure a suitable beam optics and beam diagnostics for both beamlines.

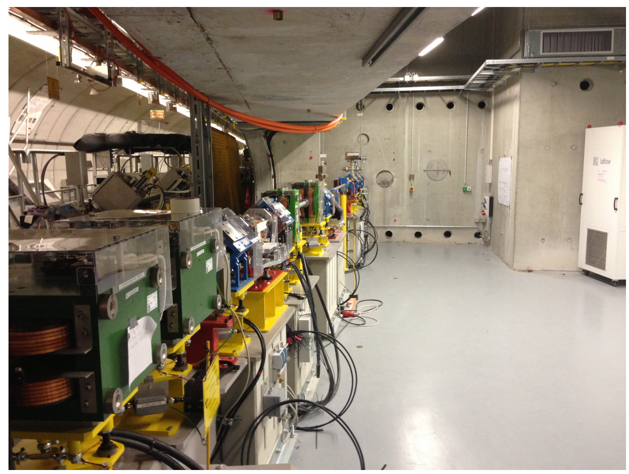

Figure 3: Part of the FLASH2 extraction beamline.

Figure 4: FLASH2 undulator beamline under construction.

The first 20 meters of the FLASH2 beamline downstream of the septum have already been mounted (Fig. 3), and the installation of the undulator beamline is on-going (Fig. 4). The electron beam commissioning of FLASH2 is scheduled to start early 2014.

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More details of the FLASH II project including the layout and operation parameters are in [6, 23–27]. The photon beamlines and diagnostics are described in [28].

OUTLOOK

The 4$^{\text{th}}$ FEL user period has been successfully finished in February 2013. After connection of the FLASH2 beamline to the FLASH linac, the re-commissioning of the FLASH facility started in summer 2013. The year 2014 is dedicated to the 5$^{\text{th}}$ user period of FLASH1.

Starting early 2014, the FLASH2 beam commissioning will take place in parallel to the FLASH1 user operation. The first FLASH2 pilot photon experiments are expected in the second half of 2014, and regular user operation in 2015.

With FLASH2 in operation, the user capacity of FLASH will be significantly increased. The variable-gap undulators will ease photon wavelength changes, and - together with two photocathode lasers and the flexible LLRF-system - allow parallel operation of FLASH1 and FLASH2 with to a certain extent independent parameters. FLASH2 operation will also profit from the latest developments of electron and photon diagnostics.

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REFERENCES

[1] W. Ackermann et al., Nature Photonics **1** (2007) 336.

[2] K. Tiedtke et al., New J. Phys. **11** (2009) 023029.

[3] S. Schreiber et al., “Status of the FLASH Facility”, Proc. FEL 2012, Nara, Japan, p. 37.

[4] M. Vogt et al., “The Free-Electron Laser FLASH at DESY”, Proc. IPAC 2013, Shanghai, China, p. 1167.

[5] K. Honkavaara et al., “Status of FLASH”, Proc. IPAC 2012, New Orleans, USA, p. 1715.

[6] K. Honkavaara et al., “Status of the FLASH II Project”, Proc. FEL 2012, Nara, Japan, p. 381.

[7] I. Will et al., Optics Express **19** (2011) 23770.

[8] S. Schreiber et al., “Upgrades of the Photoinjector Laser System at FLASH”, Proc. FEL 2012, Nara, Japan, p. 385.

[9] S. Schreiber et al., “Photocathodes at FLASH”, Proc. IPAC 2012, New Orleans, USA, p. 625.

[10] H. Schlarb, “Progress on LLRF System for FLASH & the European-XFEL”, LLRF-2011 Workshop, llrf2011.desy.de.

[11] J. Branlard et al., “LLRF Automation for the 9mA ILC Tests at FLASH”, Proc. LINAC 2012, Tel-Aviv, Israel, p. 1023.

[12] C. Schmidt et al., “Precision Regulation of RF Fields with MIMO Controllers and Cavity-Based Notch Filters”, Proc. LINAC 2012, Tel-Aviv, Israel, p. 1026.

[13] S. Schulz et al., “Femtosecond-Precision Synchronization of the Pump-Probe Optical Laser for User Experiments at FLASH”, Proc. SPIE Optics+Optoelectronics 2013, Prague, Czech Republic.

[14] C. Schmidt et al., “Feedback Strategies for Bunch Arrival Time Stabilization at FLASH Towards 10 fs”, Proc. FEL 2011, Shanghai, China, p. 531.

[15] S. Pfeiffer et al., “Fast Feedback Strategies for Longitudinal Beam Stabilization”, Proc. IPAC 2012, New Orlenas, USA, p. 26.

[16] E. Hass et al., “Longitudinal Bunch Profile Diagnostics with Coherent Radiation at FLASH”, Proc. SPIE Optics+Optoelectronics 2013, Prague, Czech Republic.

[17] C. Lechner et al., “First Direct Seeding at 38 nm”, Proc. FEL 2012, Nara, Japan, p. 197.

[18] S. Ackermann et al., “Generation of Coherent 19 nm and 38 nm Radiation at a Free-Electron Laser Directly Seeded at 38 nm”, accepted to publication in PRL.

[19] N. Stojanovic et al., “When Coherent T-rays Meet Intense fs X-rays: Enroute to Probing Ultra Fast Electric or Magnetic Field-Driven Phenomena at 4th Generation X-ray Lightsources”, in preparation.

[20] ILC Technical Design Report (2013), Vol.3, p. 80-93.

[21] J. Roensch-Schulenburg et al., “Generation of Ultra-short Electron Bunches at FLASH”, Proc. FEL 2012, Nara, Japan, p. 610.

[22] J. Roensch-Schulenburg et al., “Short SASE-FEL Pulses at FLASH”, this conference (TUPSO64).

[23] S. Schreiber et al., “Simultaneous Operation of FLASH1 and FLASH2”, this conference (TUPSO70).

[24] V. Ayvazyan et al., “FLASH II: A Project update”, Proc. FEL 2011, Shanghai, China, p. 247.

[25] B. Faatz et al., “Simultaneous Operation of a Multi Beamline FEL Facility”, Proc. FEL 2012, Nara, Japan, p. 301.

[26] M. Scholz et al., “Extraction Arc for FLASH II”, Proc. FEL 2012, Nara, Japan, p. 305.

[27] S. Ackermann et al., “Optimization of HHG Seeding at FLASH II”, Proc. FEL 2012, Nara, Japan, p. 249.

[28] E. Ploenjes et al., “FLASH2 Beamline and Photon Diagnostics Concepts”, this conference (WEPSO50).

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