STATUS OF THE FLASH FACILITY

S. Schreiber*, B. Faatz, J. Feldhaus, K. Honkavaara, R. Treusch, M. Vogt, DESY, Hamburg, Germany†

Abstract

FLASH at DESY, Hamburg is a soft X-ray free-electron laser user facility. After a 3.5 months shutdown in autumn 2011 required for civil construction for a second undulator beamline, beam operation started as scheduled in January 2012. FLASH shows again an improvement in performance with even higher single and average photon pulse energies, better stability, and significant improvements in operation procedures. The fourth user period started end of March 2012. A four months shutdown is scheduled spring 2013 to connect the second undulator beamline to the FLASH accelerator.

INTRODUCTION

FLASH [1–5], the free-electron laser (FEL) user facility at DESY, delivers high brilliance XUV and soft x-ray FEL radiation for photon experiments since summer 2005.

Besides the user operation, FLASH beam time is dedicated to improve its overall performance as an FEL user facility, e.g. on developments on the automation and stabilization, including, for example, sophisticated beam based feedbacks. Time is also reserved to set-up the photon beamlines prior to the user experiments, and to advance the photon diagnostics. In addition, part of the yearly study time is allocated for general accelerator physics experiments and developments related to future projects, in particular the European XFEL and the International Linear Collider (ILC).

In parallel to the growing user demand, the FLASH facility has been constantly upgraded. Key developments are to provide higher electron beam energies to achieve shorter photon wavelengths, improved photon beam quality as well as better stability in terms of photon pulse energy, wavelength, spectral width, pulse duration, arrival time, pointing, and wavefront quality. Synchronization of the FEL photon pulses with pump probe lasers to better than 10 fs and a reliable tool to measure photon pulse duration from 1 to 100 fs remain a hot R&D issue.

The next major upgrade underway is the construction of a second undulator beamline, the FLASH II project [6].

In this paper we summarize the present status of the FLASH facility and outline its midterm plans. Part of the material discussed here has already been presented in [5].

FLASH FACILITY

Figure 1 shows an overview of FLASH including the second undulator beamline under construction. Some of the main electron and photon beam parameters are listed in Table 1. These parameters are not all achieved simultaneously, but indicate the overall span of the performance.

Table 1: Some FLASH parameters. They are not all achieved simultaneously, but indicate the overall span of the performance.

Electron beam		
Energy (max)	MeV	1250
Peak current	kA	1 - 2
Emittance, norm. (x,y)	μm	1 - 2
Bunch charge	nC	0.06 - 1.5
Bunches / train		1 - 600
Bunch spacing	μs	1 - 25
Rep. rate	Hz	10
FEL radiation		
Wavelength (fundamental)	nm	4.2 - 45
Average single pulse energy	μJ	10 - 500
Pulse duration (fwhm)	fs	50 - 200
Spectral width (fwhm)	%	0.7 - 2
Peak power	GW	1 - 3
Photons per pulse		10^{11} - 10^{13}
Peak brilliance	*	10^{29} - 10^{31}
Average brilliance	*	10^{17} - 10^{21}

* photons / (s mrad^2 mm^2 0.1 % bw)

Trains of up to 800 high quality electron bunches are produced by a laser driven normal conducting RF-gun. Since 2010, problems have occurred related to the RF-gun and its RF-window. These issues are discussed in more detail later in this paper. The photocathode laser system is based on a mode-locked pulse train oscillator with a chain of fully diode pumped Nd:YLF amplifiers [7, 8]. The cathode is a thin film of Cs_2Te on molybdenum plugs [9].

The electron beam is accelerated up to 1.25 GeV by seven superconducting TESLA type accelerating modules. Each module has eight 1.3 GHz 9-cell niobium cavities. Downstream the first module, four 3.9 GHz (third harmonics) superconducting cavities are installed. They are used to linearize the longitudinal phase space, thus allowing operation with more regular longitudinal shaped electron bunches. The peak current required for the lasing process is achieved by compressing the electron bunches by two magnetic chicane bunch compressors at beam energies of 150 MeV and 450 MeV.

FEL radiation is produced based on the SASE (Self Amplified Spontaneous Emission) process by six undulator modules. Each of them consists of a 4.5 m long fixed gap undulator (K=1.23, period 27.3 mm, 12 mm gap) with

* siegfried.schreiber@desy.de
† for the FLASH team

ISBN 978-3-95450-123-6

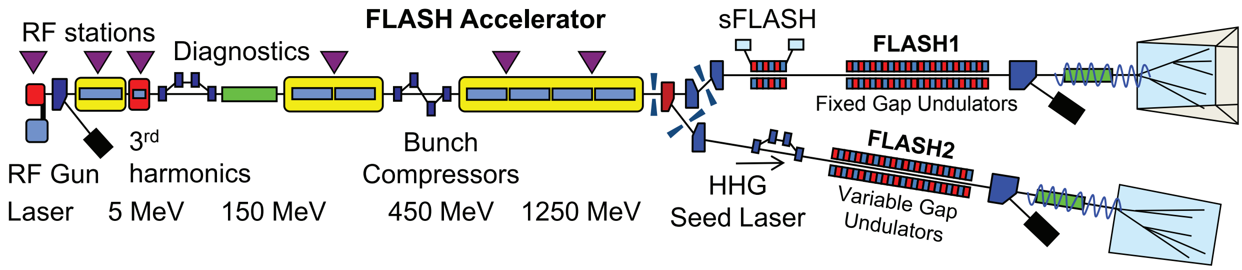

Figure 1: Layout of the FLASH facility with the new FLASH2 beamline under construction (not to scale).

permanent NdFeB magnets. A planar electromagnetic undulator downstream the SASE undulators provides THz-radiation. The photon beam, the THz-radiation, and synchrotron radiation from the last dipole magnet is transported to the experimental hall (60 m distance). New developments in photon diagnostics with the emphasis on on-line diagnostics of wavelength (spectrum), energy, and photon beam position are discussed in [10, 11].

3rd USER PERIOD 2010/2011

After the shutdown in 2009/2010 dedicated to the energy upgrade to 1.25 GeV, and the following commissioning and study period, the third user period started in September 2010. During one year of user operation, 3740 hours of FEL radiation were delivered to experiments corresponding to 75% of the total time dedicated to user runs.

More than 30 different wavelengths between 4.7 nm and 45 nm have been delivered to user experiments. About one third of the experiments requested short wavelengths below 10 nm, one third near 13.5 nm, and the last third above 20 nm. In addition, about 25% of the experiments required very short photon pulse durations (50 fs or below).[1] Roughly half of the experiments operated in single pulse mode (10 Hz repetition rate), the others used up to 300 pulses per pulse train (3000 pulses/sec) with various pulse spacings (1-25 μs). Depending on the request and on photon pulse duration and wavelength requirements, the single photon pulse energy ranges from a few 10 μJ to a few 100 μJ averaged over a shift.

Every experiment has its own demands on the photon beam parameters (photon wavelength, spectral bandwidth, pulse energy and duration, pulse train pattern). Typically two experiments run concurrently in two different photon beamlines. The photon beam is switched from one experiment to the other. In most cases, a switch is every 12 or 24 hours. Therefore, the beam parameters have to be changed often, once or occasionally even twice per day. As a consequence, a significant amount of the time (19% in third period user runs) has been needed, and whenever possible also scheduled, to tune the facility to the required performance.

Thanks to the new and improved RF-stations installed in 2010, together with the continuous effort of the DESY staff to maintain the FLASH facility, the downtime during the 3rd user period could be reduced to 4%. This is a substantial improvement compared to the previous period with total downtime of 7%. The beam time lost for users due to tuning and technical failures could mostly be compensated by contingency shifts, such that 97% of the beam time originally scheduled for experiments could also be delivered. Unfortunately, a single event in September 2011, a failure of the RF-gun window, increased the total downtime to 5.5% and lead to a premature end of the user run. Lost beamtime has been compensated in spring 2012.

OPERATION 2012

After an additional 3.5 months shutdown in autumn 2011 - due to civil construction work for the new FLASH2 undulator beamline - the FLASH operation restarted as scheduled in January 2012. During the shutdown, the FLASH facility was upgraded in several ways, e.g. improved photocathode laser beam line to provide a better transverse laser beam quality, and the installation of a 10 MW klystron giving a possibility to operate the RF-gun with a higher gradient.

SASE operation was established without problems end of January 2012 with even better performance than before: single photon pulse energies up to 500 μJ have been achieved at 13 nm wavelength. After time dedicated to FEL and accelerator studies, the 4th FEL user period started end of March 2012. During the first two user blocks, a stable SASE operation with low charge electron bunches (60 – 80 pC), to provide short photon pulses, has been successfully established for different wavelengths (13.5 nm, 21.4 nm, 44 nm).

A break-down of the RF-gun forced us to stop the operation on June-7, 2012. As a consequence, one FEL user block of four weeks has been shifted to early 2013. After a successful exchange of the RF-gun, the operation has been promptly re-established, and the next user block started as scheduled on August-13, 2012. The remaining time of this year is mainly reserved for user experiments.

Starting mid February 2013, a four months shutdown is foreseen to connect the new undulator beamline to the FLASH linac.

[1] If not otherwise stated, all photon pulse duration data are FWHH.

ISBN 978-3-95450-123-6

FEL and Accelerator Studies

One of the highlights of this year has been the seeding of sFLASH [12,13]. - the HHG (High Harmonics Generation) seeding experiment, which has been installed and commissioned at FLASH since 2010. After an upgrade of the HHG source and improvements on the diagnostics and scanning tools, sFLASH achieved its first seeding at 38 nm in spring 2012, the shortest wavelength seeded worldwide [13]

In March 2012 almost two weeks of beam time was dedicated to developments of on-line techniques to determine the electron bunch length and photon pulse duration. These studies continued in summer 2012, and also in September dedicated beam time is reserved for them. Some of the results and descriptions of different methods are in [14–17].

Some of the user experiments require very short photon pulses. This is established by operation with low charge electron bunches (<100 pC). Therefore, diagnostics of low charge electron beams is an important issue, and several developments on beam position, beam arrival time and charge monitoring, as well as on diagnostics of longitudinal beam parameters, are under way. In addition, a new project to produce ultra short pulses has been recently started [18,19]. This approach is based on the use of a short-pulse photocathode laser (<2 ps) together with a very low electron bunch charge (down to 20 pC).

The RF-gun and the accelerating modules are regulated by a sophisticated FPGA based low level RF (LLRF) system. The complete system has been upgraded in 2010/11 [20], and the next upgrade to a μTCA based system is under way. Since the stability is an import issue, continuous improvements of the synchronization system [21] and the beam arrival time stabilization including beam based longitudinal RF-feedbacks [22, 23] are on-going. Other developments of the LLRF system concern the high level controlling software, for example compensation of Lorentz force detuning, quench protection, and operation automation. Highlights are the achievements of stable beam energy to $0.5{\cdot}10^{-4}$ and arrival time stabilization to 20 fs.

Superconducting accelerators operated with long high charge electron bunch trains, like FLASH, ILC, and the European XFEL, require a sophisticated controlling hard- and software able to regulate the accelerating modules and other subsystems under heavy beam loading conditions and near their operational limits. In the framework of the so-called “ILC 9 mA experiment”, FLASH was stably operated in February 2012 with a beam energy of 1 GeV, bunch trains of up to 2400 bunches (1.5 nC / bunch) with 3 MHz bunch spacing (4.5 mA) at 5 Hz repetition rate. These studies will continue in September 2012.

Examples of other accelerator studies carried out in 2012 are an experiment based on optical diffraction radiation interference (ODRI) to develop a non-intercepting electron beam diagnostics device for high brightness high energy beams [24], and developments of beam position monitors using high order mode (HOM) signals of the 3.9 GHz cavities [25].

RF-GUN

The RF-gun (G2.0), which was in operation at FLASH since 2004, was replaced by a new dry-ice cleaned RF-gun (G4.2) during the 2009/2010 shutdown. The dry-ice cleaning technique developed for superconducting cavities reduced the dark current of the gun body by a factor of 10 for nominal operation conditions at FLASH. This is a prerequisite to operate the new third harmonic cavities downstream the gun. A maximum of a few microamperes of dark current is allowed to be lost in the superconducting cavities of the third harmonic module. Indeed, the dark current of the new gun is with 20 to 30 μA sufficiently small. A kicker system together with a collimator at 5 MeV just before the first accelerating module reduces the dark current lost in the superconducting cavities to an operable amount.

Together with the new RF-gun, a new RF-window design has been used, which uses a Conflat-like gaskets for easier vacuum connection. It turned out, that the whole batch of new windows had a too thin TiN coating causing permanent electron field emission from the ceramics larger by two orders of magnitudes than expected. The RF-window is separating the RF-gun vacuum from the RF-waveguides, filled with SF_6 gas at normal pressure. The electron emission caused a permanent emission of visible light and frequently triggered discharge processes close to the window leading to frequent trips of the RF. Since the recovery time from a trip is about 1 hour, 17 trips per week would cause an unacceptable 10% of downtime. The long recovery time is determined by the average RF power, FLASH design is to run with 34 kW of average power. Reducing the average power to 20 kW by reducing the RF pulse length to 500 μs initially lead to uncomfortable but acceptable running conditions. Unfortunately, just ten days before the scheduled end of the third user period, a large breakdown event at the RF window prevented the RF gun to be operated with the required RF power of 4 MW forcing us to prematurely stop the user run.

Since the whole batch of windows showed an insufficient TiN coating, we decided to use a window of the previous batch. It was operated at the previous RF-gun (G2.0) at FLASH from 2004-2009 and was known to work up to 3 MW without any problem. A performance test in the last days before the 2011 shutdown showed the normal expected behavior on start-up, very small electron emission yield and a short conditioning time up to 4 MW. We did not attempt to further increase the RF power beyond the present FLASH design parameters. After restart in January 2012, we could bring-up the RF-gun running stably with 600 μs RF-pulse length at 4 MW RF-power (10 Hz). Initially the trip rate was with a few trips per months as small as required for reliable operation of FLASH.

Unfortunately, during the second user block of the forth user period in May 2012, this time the RF-gun itself, showed serious arcing at the backplane close to the cathode RF contact spring. After finishing up the second user block, we exchanged the gun by the one being operated

ISBN 978-3-95450-123-6

at PITZ (G4.1). Postmortem investigation of the RF-gun body revealed a damage of the copper lip close to the RF-contact spring causing arcing in the small gap of the gun body to the cathode plug.

With careful planning and a tremendous effort by the DESY staff in Hamburg and Zeuthen, only two weeks of shutdown was required to exchange the RF-gun.

The RF-gun (G4.1) has been operated at PITZ (DESY, Zeuthen) in 2011/12 [26]. Unfortunately, it was equipped with an RF-window from the faulty batch. Therefore, we changed to the old well-known window of gun G2.0. The gun started up quickly and achieved nominal RF parameters in a few days only.

Presently, we run the gun with an average power of 26 kW. The trip rate with 4 MW RF power and 650 μs pulse length, and 10 Hz repetition rate is not yet measurable; since start-up, no trip has been detected yet. The dark current measured at the gun exist for nominal solenoid field (0.17 T) started a bit high with initially 50 μA. After a couple of days, the dark current is now stable below 10 μA.

FLASH II PROJECT

The extension of the FLASH facility (FLASH II Project) is under way. The upgrade includes a second undulator beamline with variable gap undulators located in a new building, and a new experimental hall for photon beamlines and experiments (Fig. 1). The FLASH linac drives both undulator beamlines: the present FLASH1 undulator and the new FLASH2 beamline. The wavelength range of FLASH2 will be similar to FLASH1: 4 nm - 60 nm.

The civil construction started in autumn 2011 and will continue until spring 2013. The mounting of the FLASH2 beamline starts end of 2012; the new beamline will be connected to the FLASH linac in spring 2013. The beam commissioning is scheduled for the second half of 2013.

More details of the FLASH II project including FLASH2 layout and parameters are in [6, 27–30].

SUMMARY AND OUTLOOK

FLASH finished its third successful FEL user period in September 2011. After a 3.5 months shutdown, FLASH restarted as scheduled in January 2012. The year 2012 is mainly scheduled for user experiments.

Due to the RF-gun failure in June 2012, a four weeks block of user experiments has been moved to early 2013. After the successful exchange of the RF-gun, FLASH was back in regular beam operation mid July 2012, and the user experiments continued with the fourth user block of the forth period as scheduled in mid August 2012.

FLASH2 will be connected to the FLASH linac during a four months shutdown in spring 2013. The commissioning of FLASH2 will take place parallel to the FLASH1 user operation in 2013.

ACKNOWLEDGMENT

We like to thank all colleagues, both at DESY and in the collaborating institutes, who are participating in the successful operation, meticulous maintenance, and continuous upgrading of the FLASH facility. We are especially grateful for the outstanding effort of DESY staff, Hamburg and Zeuthen, lead by S. Lederer, in successfully exchanging the RF gun on the spot keeping a tight and demanding schedule.

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., Proc. FEL 2011, Shanghai, China, p. 267.
[4] M. Vogt et al., Proc. IPAC 2011, San Sebastián, Spain, p. 3080.
[5] K. Honkavaara et al., Proc. IPAC 2012, New Orleans, USA, p. 1715.
[6] K. Honkavaara et al., this conference, WEPD07.
[7] I. Will et al., Optics Express **19** (2011) 23770.
[8] S. Schreiber et al., this conference, WEPD08.
[9] S. Schreiber et al., Proc. IPAC 2012, New Orleans, USA, p. 625.
[10] G. Brenner et al., this conference, THPD35.
[11] M. Braune et al., this conference, THPD36.
[12] S. Ackermann et al., Proc. IPAC 2011, San Sebastian, Spain, p. 923.
[13] C. Lechner et al., this conference, TUOAI01.
[14] N. Stojanovic et al., this conference, THOC02.
[15] A. Cavalieri et al., this conference, TUOB03.
[16] S. Serkez et al., this conference, THPD34.
[17] N. Stojanovic et al., this conference, THPD46.
[18] M. Rehders et al., Proc. IPAC 2012, New Orlenas, USA, p. 1718.
[19] J. Roensch-Schulenburg et al., this conference, THPD33.
[20] H. Schlarb, "Progress on LLRF System for FLASH & the European-XFEL", LLRF-2011 Workshop, llrf2011.desy.de.
[21] S. Schulz et al., Proc. FEL 2010, Malmö, Sweden, p. 581.
[22] C. Schmidt et al., Proc. FEL 2011, Shanghai, China, p. 531.
[23] S. Pfeiffer et al., Proc. IPAC 2012, New Orlenas, USA, p. 26.
[24] A. Cianchi et al., this conference, WEOB02.
[25] P. Zhang et al., Proc. IPAC 2011, San Sebastian, Spain, p. 2891.
[26] M. Krasilnikov et al., this conference, MOPD59.
[27] V. Ayvazyan et al., Proc. FEL 2011, Shanghai, China, p. 247.
[28] B. Faatz et al., this conference, TUPD32.
[29] M. Scholz et al., this conference, TUPD33.
[30] S. Ackermann et al., this conference, TUPD11.

ISBN 978-3-95450-123-6