STATUS OF FLASH

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Abstract

FLASH at DESY (Hamburg, Germany) is a free-electron laser user facility driven by a superconducting 1.25 GeV linac based on TESLA technology. During the 3rd user period from September 2010 to September 2011, 3740 hours of FEL radiation were delivered to FEL experiments at more than 30 different wavelengths between 4.7 nm and 45 nm. In addition, beam time has been dedicated to general accelerator and FEL physics studies and developments related to the future projects like the European XFEL and the International Linac Collider. After a 3.5 months shutdown in autumn 2011 due to civil construction for a second undulator beamline - FLASH2 - and a following commissioning and study period, 2012 is mainly dedicated to FEL user experiments. This paper reports the operation status of the FLASH facility and summarizes the studies carried out in 2011 and early 2012. The mid-term plans including FLASH2 are presented as well.

INTRODUCTION

FLASH [1–4], 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. In addition, FLASH provides beam time for developments on diagnostics, controlling and stabilization of electron and photon beams, as well as for general FEL and accelerator physics studies. This combination of being simultaneously an FEL user facility and a test bench for new developments makes FLASH a unique facility in the world.

FLASH FACILITY

FLASH consists of an injector to produce high quality electron bunches, a superconducting linac to accelerate the electron beam up to 1.25 GeV, and an undulator section to produce SASE (Self Amplified Spontaneous Emission) FEL radiation. The total length of the FLASH facility including the experimental hall is about 315 meters. The main electron and photon beam parameters during the FEL user operation in 2011 are listed in Table 1. The parameters shown indicate the overall span of the performance, i.e. all these parameters are not achieved simultaneously.

Electron bunch trains are produced by a laser driven normal conducting RF-gun. The photocathode laser system is based on a mode-locked pulse train oscillator with a chain of fully diode pumped Nd:YLF amplifiers [5] . The UV laser beam is guided onto a Cs_2Te cathode [6] locked at the backplane of the RF-gun.

Table 1: FLASH Parameters 2011 (FEL User Operation)

Electron beam		
Energy (max)	MeV	1250
Peak current	kA	1 - 2
Emittance, norm. (x,y)	μmrad	1 - 2
Bunch charge	nC	0.1 - 1
Bunches / train		1 - 500
Bunch spacing	μs	1 - 25
Rep. rate	Hz	10
FEL radiation		
Wavelength (fundamental)	nm	4.1 - 45
Average single pulse energy	μJ	10 - 400
Pulse duration (fwhm)	fs	50 - 200
Spectral width (fwhm)	%	0.7 - 2
Peak power	GW	1 - 3
Peak brilliance	*	10^{29} - 10^{31}
Average brilliance	*	10^{17} - 10^{21}

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

The FLASH linac has seven TESLA type superconducting accelerating modules operated at 1.3 GHz. In addition, a module with four 3.9 GHz superconducting cavities is installed downstream of the first module to linearize the longitudinal phase space. Two magnetic chicane bunch compressors at 150 MeV and 450 MeV are used to achieve the required peak current.

The SASE FEL radiation is produced by six 4.5 m long fixed gap undulators (K=1.23) consisting of permanent NdFeB magnets. On request, THz radiation, from a planar electromagnetic undulator located downstream the SASE undulators, is also available.

FLASH USER OPERATION

Third User Period

During the third user period (Sep 2010 - Sep 2011), 3740 hours of FEL radiation were delivered to user experiments. This corresponds to 75% of the total time dedicated to user runs. Every experiment has its own demands on the photon beam parameters (photon wavelength, spectral bandwidth, pulse energy and duration, pulse train pattern). Therefore the parameters had often to be changed once or sometimes even twice per day. As a consequence, a significant amount of the time (19%) was needed, and whenever possible also scheduled, to tune the facility for the required performance. During the 3rd user period the downtime could be kept at the 4% level, a substantial improvement compared to the previous user period with a downtime of 7%. This reduc-

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tion is mainly due to the new and improved RF-stations installed in 2010, and because of the continuous effort of DESY staff to maintain the FLASH facility. Unfortunately, a single event in September 2011, a failure of the RF-gun window, increased the total downtime to 5.5%. The beam time lost due to tuning and technical failures could, however, be mostly compensated by contingency shifts such that 97% of the beam time originally scheduled for experiments could also be delivered.

During the third user period more than 30 different wavelengths between 4.7 nm and 45 nm have been provided. About one third of the experiments used short wavelengths below 10 nm, one third near 13.5 nm, and the last third above 20 nm. Roughly half of the experiments operated in a single pulse mode, the second half requested multi-pulse operation with different pulse spacings. About 25% of the experiments required also very short pulse durations (50 fs or below).

Figure 1 shows an example of a multi-pulse operation: 300 photon pulses with 1 μs spacing at a wavelength of 6.9 nm with an average power exceeding 300 mW. A similar performance has also been obtained at 4.7 nm.

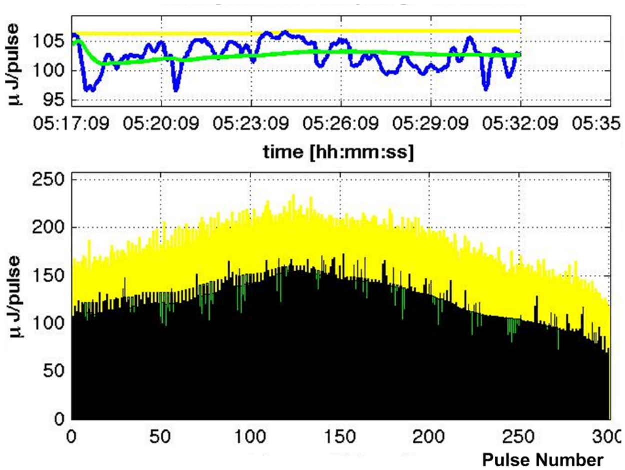

Figure 1: FEL pulse train of 300 pulses with 1 MHz repetition rate at a wavelength of 6.9 nm. The Photon pulse energy is measured by a gas-monitor detector. Blue: actual value, Yellow: maximum, Green: average.

Status Spring 2012

In autumn 2011, a 3.5 months interruption of FLASH operation was required due to civil construction for the new undulator beamline. During the shutdown, only minor technical modifications have been made at the FLASH facility. The most important upgrades are the improvement of the 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.

FLASH operation restarted in January 2012, and SASE operation was established without problems by end of the month. FLASH shows now even better performance than before: single photon pulse energies up to 500 μJ have been achieved at 13 nm wavelength. After a period dedicated to FEL and accelerator studies, the 4$^{\rm th}$ FEL user period started end of March 2012. During the first user block, a stable SASE operation with low charge electron bunches (80 pC), to provide short photon pulses, has been successfully established.

RF-GUN WINDOW

The RF-window separating the RF-gun vacuum from the RF-waveguides (partially filled with SF_6 gas at normal pressure) has caused problems since 2010. Due to a very high interlock rate preventing a stable operation, the window was exchanged in June 2010. Despite a continuous high level of light emission from the new window, it was possible to operate the RF-gun and steadily increase the RF-pulse length up to 500 μs. Unfortunately, the window failed only ten days before the scheduled end of the user run. The failure reason is most likely related to the window coating. The window was exchanged right away by a window from an old RF-gun (in operation at FLASH 2004-2009), and also tested in the last days before the shutdown showing a normal expected behavior. After a short conditioning period early 2012, the RF-gun is now running stably with 600 μs RF-pulse length at 4 MW RF-power (10 Hz).

FLASH II PROJECT

Upgrading of the FLASH facility (FLASH II project) is under way. The upgrade includes a second undulator beamline with variable gap undulators to allow a more flexible operation, and a new experimental hall for photon beamlines and experiments. The FLASH linac will drive both undulator beamlines: the present (FLASH1) undulator and the new one (FLASH2). The wavelength range of FLASH2 is similar to FLASH1: 4 nm - 60 nm.

Civil construction of the new buildings started in autumn 2011 and continues in several steps until early 2013. The electron beamline design is mostly finished, and the manufacturing of the components is on-going. The beamline mounting starts in autumn 2012. Early 2013 the new beamline will be connected to the FLASH linac during a four months shutdown. Commissioning of FLASH2 with beam is scheduled for the second half of 2013. Parallel to it, FLASH1 will provide FEL radiation for user experiments.

FEL AND ACCELERATOR STUDIES

In addition to FEL user operation, FLASH beam time is allocated to FEL and accelerator studies. The highest priority during the study periods is on improvements of the FLASH performance as an FEL user facility, e.g. , on automatizing and stabilizing the FEL operation, including for example sophisticated beam based feedbacks. Part of the time is always reserved to set-up the photon beamlines and to advance the photon diagnostics. Training of the

FLASH operators is also an important issue. About 15% of the yearly study time is reserved for general accelerator physics experiments and developments related to future projects, in particular the European XFEL and the International Linear Collider (ILC).

Since 2010 a HHG seeding experiment sFLASH [7] has been installed and commissioned at FLASH. After an upgrade of the HHG source and improvements on the diagnostics and scanning tools, sFLASH achieved its first seeding end of April 2012 [8].

Part of the FEL user experiments require very short photon pulses (below 50 fs). In order to realize this, bunch compression studies and developments of on-line techniques to determine both the electron bunch length and photon pulse duration are on-going. In March 2012 almost two weeks of beam time have been especially dedicated to these studies, and they continue with a high priority also in the coming study periods.

Diagnostics of low charge electron beams (< 100 pC) is an important issue, and several developments on beam position, beam arrival time and charge monitoring, as well as on longitudinal beam diagnostics, are under way. In addition, a new project [9], aiming to produce ultra short bunches by using a short-pulse photocathode laser and very low electron charge (down to 20 pC), has recently started.

The RF-gun and the accelerating modules are regulated by a sophisticated FPGA based low level RF (LLRF) system. During the last years, a substantial amount of study time has been allocated to developments related to this system. The complete system has been upgraded in 2010/11 [10], and the next upgrade to a μTCA based system is foreseen later this year. Developments are on-going on the high level controlling software as well, for example concerning compensation of Lorentz force detuning, quench protection, and operation automation. Important issues are also the improvements of the synchronization system [11] and the beam arrival time stabilization including beam based longitudinal RF-feedbacks [12, 13].

Operation with a heavy beam loading is an important issue for superconducting accelerators with long high charge bunch trains, like FLASH, ILC, and the European XFEL. Since 2008, FLASH beam time has been regularly reserved for these studies ('ILC 9 mA experiment'). During the study block in February 2012 FLASH was stably operated with bunch trains of up to 2400 bunches (1.5 nC / bunch) with 3 MHz bunch spacing (4.5 mA) at 5 Hz repetition rate. Several dedicated studies, e.g., operation of the superconducting cavities near their quench limits, have been successfully carried out. These studies will continue in September 2012.

An experiment based on optical diffraction radiation interference (ODRI) [14] to develop a non-intercepting electron beam diagnostics device for high brightness high energy beams has been located in the FLASH by-pass line since 2006. In February 2012 its final measurements have been carried out [15] before moving it next year to FLASH2. Other examples of studies carried out during accelerator study periods are an experiment to generate electron bunches with linearly-ramped current profile [16], and developments of beam position monitors using high order mode (HOM) signals of the 3.9 GHz cavities [17].

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 with a very good performance: single photon pulse energies up to 500 μJ are achieved at 13 nm wavelength. The year 2012 is mainly devoted to user experiments. A four months shutdown is scheduled early 2013 to connect the new FLASH2 beamline to the FLASH linac.

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