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STATUS OF THE FREE ELECTRON LASER USER FACILITY FLASH

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Abstract

FLASH, the free electron laser user facility at DESY (Hamburg, Germany), delivers high brilliance XUV and soft x-ray FEL radiation to photon experiments. After a shutdown to connect the second undulator beam line FLASH2 to the FLASH linac, recommissioning of FLASH started in autumn 2013. The year 2014 is dedicated to FLASH1 user experiments. The commissioning of the FLASH2 beam line takes place in 2014 in parallel to FLASH1 operation.

INTRODUCTION

FLASH [1–3] is a superconducting linac with an RF photo cathode gun driving a SASE FEL in the XUV and soft-x-ray regime. Every year this facility attracts more than 100 scientists from all over the world and a selection of publications based on science at FLASH can be found in [4]. To be able to provide FEL radiation to more users, a second beam line (FLASH2) [5,6] was built during 2012 and 2013. In 2013 FLASH had a 6 months shutdown to connect FLASH2 to the FLASH linac. The remainder of 2013 was spent for commissioning the new μTCA based low level RF (LLRF) system, recommissioning of the FLASH linac and the FLASH1 beam line, including an extensive survey campaign. The latter had become necessary because of the effects of ground motion (up to 10 mm vertical displacement) due to civil construction for FLASH2. During January 2014 the personnel interlock system of FLASH2 was integrated into the FLASH system. The official permission to operate FLASH2 was renewed on February 7th of 2014.

THE UPGRADED FLASH FACILITY

The first part of FLASH (common to both beam lines) is a 150 m long section including the photo injector, the superconducting linac and two bunch compressors. In the following we will often overuse the name "FLASH" with the facility as a whole and this common part. The beams are then separated into the two beam lines FLASH1 and FLASH2. A schematic layout of FLASH is shown in Fig. 1, and some of its key parameters are listed in Table 1.

The key technology of FLASH is in the seven 1.3 GHz (L-band) accelerating modules with 8 nine-cell niobium cavities each. Their maximum energy gain per module ranges from 180 MeV (older modules) to 240 MeV (latest XFEL prototype). In contrast to normalconducting linacs the superconducting technology allows a duty factor of 1.5 % at the highest possible gradients, i.e. ten RF flat tops with a usable duration of 800 μs per second. At a bunch frequency of 1 MHz, FLASH can thus provide a maximum of 8000 bunches/s. The long RF flat tops offer the unique opportunity to split each bunch train and serve two (or more) beam lines with a fraction of the maximum number of bunches per train at an unchanged burst rate of 10 Hz.

Table 1: FLASH Parameters 2013/2014

e$^-$:			
emittance	$\beta\gamma\varepsilon_{x,y}$		
(1 nC, on-crest, 90% rms)		1.4	mm mrad
charge		0.08 - 1.0	nC
peak current		0.8 - 2.0	kA
beam energy		380 - 1250	MeV
bunches / train		1 - 450	
bunch spacing		1 - 25	μs
train repetition frequency		10	Hz
γ (FLASH1):			
wavelength (fundamental)		4.2 - 45	nm
average single pulse energy		10 - 540	μJ
pulse duration (fwhm)		<30 - 200	fs
spectral width (fwhm)		0.7 - 2.0	%
peak power		1 - 3	GW
peak brilliance		10^{29} - 10^{31}	(+)
average brilliance		10^{17} - 10^{21}	(+)
(+) : photons/(s mm^2 mrad^2 0.1%bw)			

In order to provide bunch patterns and charges independently for the two sub trains, FLASH operates two separate photo injector lasers. Electron bunches are generated by photo emission induced by UV laser pulses of 262 nm wavelength on a Cs_2Te cathode at the back plane of a normal-conducting 1.6 cell 1.3 GHz copper cavity [7, 8]. The laser spots on the cathode are transversely approximately flat with a typical diameter of 1.2 mm (0.7 mm - 3 mm). They are longitudinally approximately Gaussian with a sigma of 6 - 7 ps.

The bunches are compressed in two stages. Each stage consists in off-crest operated RF inducing an energy chirp along the bunch and an adjacent magnetic dipole chicane which compresses the charge density through path length differences in the dispersive structure. A superconducting 3.9 GHz 3rd harmonic module with 4 cavities produced at Fermilab is used for linearizing the compression. In order to allow different compression schemes for different beam requirements in FLASH1/2, the flat tops of all RF stations can be split into 2 (or more) sub flat tops with moderately different parameters (amplitude, phase). Currently, a gap of $\sim$ 50 μs between the sub trains is sufficient for 5° - 10° phase split and the corresponding amplitude correction for equal energy of both beams.

After the last module beams can be provided with energies between about 380 MeV to 1250 MeV. The FLASH2 beam is kicked by two (+ one spare) vertical flat top kick-

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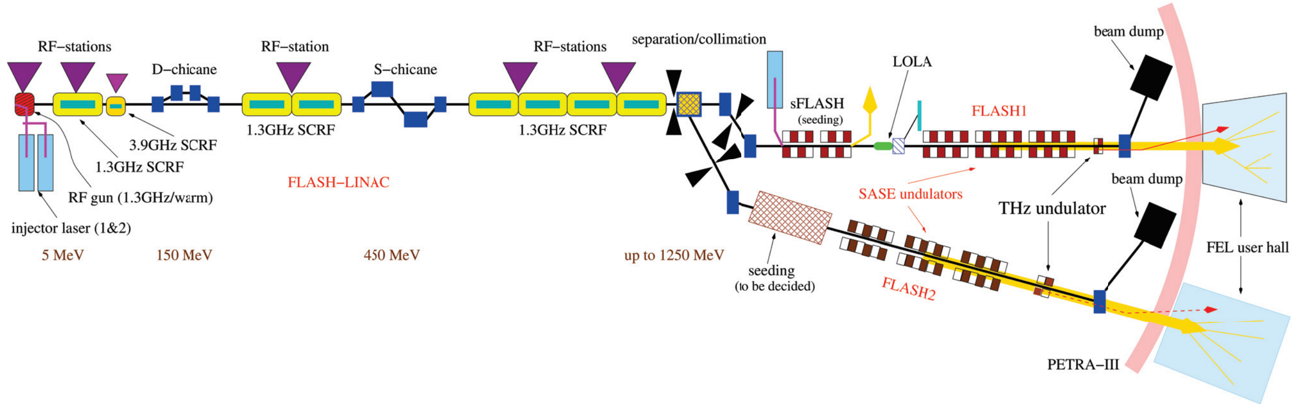

Figure 1: Schematic FLASH layout including beam lines FLASH1 and FLASH2.

ers by a total angle of 2.2 mrad. The dipolar kicks from the offsets in the (still common) 3 downstream quadrupoles deflect the FLASH2 reference trajectory straight into the entrance of the horizontally deflecting channel of a Lambertson septum, thereby producing a vertical offset of 20 mm w.r.t. the FLASH1 reference trajectory. The septum deflects the FLASH2 beam by 6.5° into the FLASH2 extraction arc which separates FLASH2 from FLASH1 and which closes the horizontal and vertical dispersion and R_{56}. The FLASH1 beam traverses the kickers either before or after the FLASH2 flat top, and the gap needed for stable beams in both channels is about 30 μs. The FLASH1 beam line also starts as a dispersive arc ("dogleg"). The first (common) transverse collimator is directly upstream the extraction kickers. Each beam line contains two energy collimators in the the dispersive arcs.

FLASH1 contains a section devoted to seeding experiments (sFLASH) [9]. So far, no final decision has been made on the optimum seeding scheme and the necessary hardware for FLASH2. The section directly downstream to the extraction arc is reserved for future seeding installations. In FLASH1 a vertically deflecting traveling wave RF structure, originally manufactured at SLAC, and called LOLA, is installed between sFLASH and the main SASE undulator. LOLA can be operated in two modes: The 1st mode is destructive because the beam (at most 2 bunches) is bend horizontally by 5.5° by a DC magnet. This mode maps the longitudinal phase space onto x-y space on a screen [10]. In the 2nd minimally invasive mode, a horizontal kicker deflects an arbitrary selected bunch onto an off axis screen, allowing for calibrated "live" bunch length measurements [11].

The FLASH1 SASE undulator is made from six 4.5 m long fixed gap undulators. Thus the wavelength of the FEL radiation can only be changed via the beam energy (see Table 1). The undulators are interleaved with quadrupoles, nowadays powered as a FODO structure. In FLASH2 the SASE radiation is produced by eleven 2.39 m long variable gap undulators also interleaved with a FODO focusing structure. At a beam energy of 700 MeV (corresponding to the quite popular wavelength of 13.5 nm in FLASH1) FLASH2 spans the wavelength range from 10 to 40 nm. FLASH1 is and FLASH2 will be equipped with a THz undulator used for pump-probe experiments and for γ diagnostics.

USER OPERATION

Typically about one third of the experiments request short wavelengths below 10 nm, one third near 13.5 nm, and the last third above 20 nm. Roughly half of the experiments operate in a single bunch mode, and the other half request multi bunch operation with various bunch numbers and spacings. About 25% of the experiments require very short photon pulse durations (50 fs or below). A more detailed table showing the variability of user requests can be found e.g. in [2].

HIGHLIGHTS

In order to establish a beam waist in the FLASH2 extraction septum needed to minimize the emittance dilution due to coherent synchrotron radiation of the compressed bunches in the strongly deflecting septum, it became necessary to modify the optics in the main linac section (Fig. 1 : ACC4/5/6/7) [12, 13]. In doing so we took the opportunity to convert the original doublet optics into a chromatically more relaxed FODO optics at the cost of slightly increased β-functions in the cold modules. The recommissioning of the affected FLASH1 sections was completely unproblematic and in this new optics a new record SASE intensity of 540 μJ at 8.7 nm in single bunch mode with 0.6 nC charge was achieved during user preparation on February 8th.

After commissioning the new μTCA.4 based LLRF system (developed also for the European X-FEL), energy and phase jitter were reduced by roughly a factor of 2 even without beam based feedbacks active [14]. Reduced pulse to pulse jitter of the RF flat tops improves the stability of the SASE intensity. More uniform RF flat tops improve the uniformity of the FEL radiation parameters over long bunch trains. Moreover, reducing the photon arrival time jitter which is mainly caused by beam energy fluctuations directly improves the resolution of time resolved experiments.

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RF-GUN ISSUES

Since 2010 the RF gun has been operated with 10 Hz RF pulse repetition frequency, long flat tops (> 400 μs) and with an increased RF forward power >4 MW. Since then we observe a non negligible source of downtime [1–3]. Two recurring key problems have been identified: (1) Electrical discharge in the gap between the cavity back plane and the (retractable) cathode plug erodes and finally destroys the RF contact and the cavity back plane. (2) Unpredictable bursts of vacuum, light and multipacting activity on or close to the vacuum side of the RF window. Problem (1) was attacked by a redesign of the back plane / cathode plug section. The first gun with this new design is currently installed at the injector of the European X-FEL and due to the short commissioning time no conclusive results are available yet. The first generation of RF windows in use for the FLASH RF gun were (in-house) modified from coupler windows for cold modules. The vacuum side of the ceramics was sputtered with a thin TiN layer. In addition, several RF windows of a different type were ordered from the industry.

After the 2013 shutdown a gun with the old back plane design and equipped with an industrial type RF window was installed. After 2 weeks of conditioning, this gun could be operated stably until mid October 2013. Then during a regular start up procedure suddenly strong multipacting occurred and the gun could only be stabilized after 24h of conditioning. Most likely a vacuum leak started developing from this point. Finally it was decided not to take the risk of a catastrophic vacuum event and instead replace the window. At that time there were no equivalent industry built windows accessible, so we switched back to the in-house type. The first replacement, although well behaved on a test bench in traveling wave mode could not be conditioned and after 1 week it was again replaced with an equivalent window. Conditioning went only marginally better and required running with initially extremely short RF pulses (10 μs flat top). This combination of gun and window is in operation since then and we have so far achieved a flat top duration of 450 μs.

FLASH2 COMMISSIONING

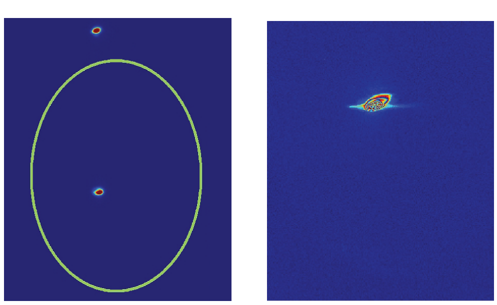

Figure 2: Left: bunch for FLASH1 (bottom) and bunch for FLASH2 (top) right before extraction septum. Right: bunch at FLASH2 dump screen. Beam dimensions are not to scale.

The commissioning of FLASH2 has been delayed due to late construction of the buildings and infrastructure causing the expected ground motion of the FLASH1 beam line taking place during the commissioning time. This forced a survey and realignment of 100 m of the FLASH 1 beam line of several weeks.

First beam was extracted through the septum on March 4th. Figure 2 (left) shows the screen right before the septum with the FLASH1 beam (bottom) and the FLASH2 beam (top). We achieved first beam at the FLASH2 dump on May 23th, see Fig. 2 (right).

ACKNOWLEDGMENTS

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