SIMULTANEOUS OPERATION OF TWO UNDULATOR BEAMLINES AT FLASH

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Abstract

In the last few years, first tests have been performed to show that two FLASH undulator lines can deliver FEL radiation simultaneously to users with a large variety of parameters, such as radiation wavelength, pulse duration, intra-bunch spacing etc. In order to achieve this, FLASH has the possibility to have two injector lasers on the cathode of the gun with different parameters, and the accelerator can vary gradient and phase within one RF-pulse to guarantee optimal performance for both beamlines. In this contribution, we show the flexibility which can be achieved with this system.

INTRODUCTION

FLASH, the free-electron laser at DESY in Germany has been in operation as a user facility since summer 2005 [1]. Since then, the request for beamtime has been growing steadily over the years, with a factor of 4 overbooking in the recent user periods. A description of the FLASH facility can be found in Ref. [2].

In order to meet the increased demand, a study started in 2006 to look at the feasibility to add an undulator line to the existing accelerator. In order to double the beamtime, both users would need the 10 Hz repetition rate. A fast kicker in combination with a DC septum is used to deflect the beam into the second undulator line. In addition, the large variety in beam parameters should be possible at both beamlines independently in order to ensure a maximum flexibility in planning of the beamtime. For this reason, it was decided to use two cathode lasers, each with its own bunch train. A variable delay between the two lasers within the RF pulse of gun and modules ensures that the two users get their own set of parameters. In addition, the start time of kicker pulse is shifted with the start time of the laser pulse and the RF-phase and amplitude of gun and each of the modules can be tuned for optimal conditions for both users.

The layout of the facility including the new beamline is described in Ref. [2] and shown in Fig. 1. In addition to a new undulator line with variable gap undulators, a new experimental hall has been built which has space for an additional 5 to 7 experimental stations. In Table 1, the parameters expected for FLASH2 are shown. They are similar to those for FLASH with the exception of the energy spread, which is increased due to coherent synchrotron radiation and the large separation angle of 12° [3, 4].

That the RF-system is able to handle the flexibility needed to compress the beam independently for FLASH1 and FLASH2 has already been presented earlier [5]. Also the fast kicker system has been tested and is behaving according to specifications. What we want to present in this paper is that we are able to get two independent bunch trains to radiate with different charges and a variable delay in time.

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Table 1: Expected Parameters for FLASH2

Electron Beam	**Value**
Energy Range	0.5 – 1.25 GeV
Peak Current	2.5 kA
Bunch Charge	0.02 - 1 nC
Normalized Emittance	1.4 mm mrad
Energy Spread	0.5 MeV
Average β-function	6 m
Rep. rate	10 Hz
Bunch separation	1-25 µs
Undulator	**Value**
Period	31.4 mm
K	0.5 - 2
Segment length	2.5 m
Number of segments	12
Photon Beam SASE	**Value**
Wavelength range (fundamental)	4 - 60 nm
Average single pulse energy	1 - 500 µJ
Pulse duration (FWHM)	10 - 200 fs
Peak power (from av.)	1 - 5 GW
Spectral width (FWHM)	≈ 0.5 - 2 %
Peak Brilliance	10^{28} - 10^{31} B

SIMULTANEOUS OPERATION OF FLASH1 AND FLASH2.

User demands vary in almost all respects. A significant increase in beam time can only be achieved, if the parameters between the two undulator lines can be varied independently. For the wavelength, this is clear and straightforward. For other parameters, such as the bunch length, this is not so trivial. Figure 2 shows, how the bunch length was varied by varying the charge. The measurements were performed with a standard diagnostics implemented in FLASH1 and foreseen for FLASH2 [6, 7].

The next tests show the possibility to produce SASE for different parameters. For these tests, only RF parameters were changed within the RF-pulse and orbit was adjusted behind the FLASH2 extraction point. Because the FLASH2 beam line was under construction, the tests presented in this section were all performed at FLASH1. This means, that a certain freedom, which one normally has for lasing with two pulse trains, such as adjustment of orbit and optics in the part of the machine which the beamlines do not have in common, is not available for these tests.

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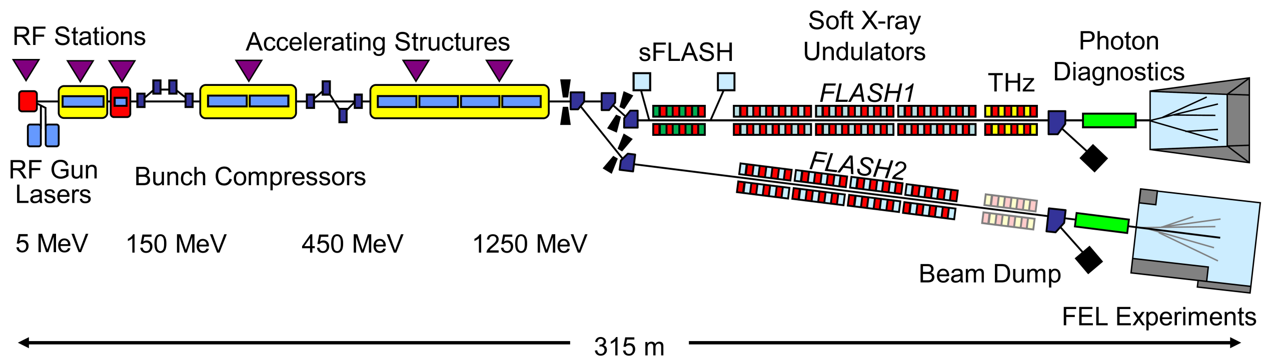

Figure 1: Schematic layout of the FLASH facility. The electron gun is on the left, the experimental hall on the right. Behind the last accelerating module, the beam is switched between FLASH1, which is the present undulator line, and FLASH2, which is the upgrade.

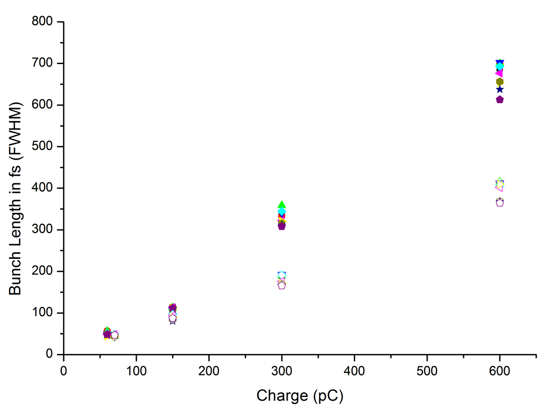

Figure 2: Bunch length for different charges. Measurements have been performed for a beam energy of 0.7 (top) and 1.1 GeV (bottom)

Table 2 shows the SASE level, which was achieved at these different bunch lengths. For the same compression, one would assume that the SASE level is proportional to the charge. As can be seen, towards higher charge, the pulse energy does not increase anymore linearly. A reason could be that space charge reduces the peak current and therefore the pulse energy. For the high energy of 1.1 GeV, corresponding to around 5 nm in FLASH1, optimization of the orbit in the undulator is needed, which may not be equally good for each charge. Details can be found in Ref. [8].

Table 2: SASE Level for Different Charges and Bunch Lengths

Charge in nC	SASE 0.7 GeV in µJ	SASE at 1.1 GeV in µJ
0.6	200	165
0.3	170	90
0.15	110	75
0.07	40	35

So far, all tests were performed with a single injector laser. The next tests show lasing with two injector lasers, separated in time by 80 μs.

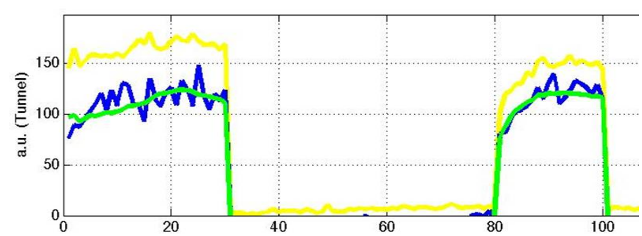

Figure 3: Lasing of two bunch trains with the same charge of about 0.5 nC. The horizontal scale is µs. The blue line indicates the actual SASE pulse energy produced by each individual electron bunch in the macro pulse. The green line is the time average of this signal. The yellow line indicated the maximum SASE level which occured since the measurement was started.

Figure 3 shows lasing of the two bunch trains in the SASE undulators in FLASH1 with the same charge of around 0.5 nC. In the example shown here, both bunch trains have a repetition rate of 1 MHz. The number of bunches in this case was 30 and 20 respectively. As can be seen, the SASE level is more or less equal. Great care was taken to make sure that both injector lasers hit the cathode on the same spot and under the same angle to make sure that the electron beams have the same trajectory. This condition will be relaxed in the later situation, since the orbit in the FLASH1 and FLASH2 undulators can be adjusted independently to optimize lasing.

In Fig. 4, the charge of the second bunch train was reduced by a factor of 2. In order get SASE at the level shown in Fig. 5, mainly compression phases had to be adjusted in the second part of the RF-pulse. The entire change was done in a matter of minutes, mainly given by finding the new optimum in compression settings. As can be seen, the first pulse train was not changed.

A more accurate characterization of both bunch trains has not been done. Of special interest is, what the difference

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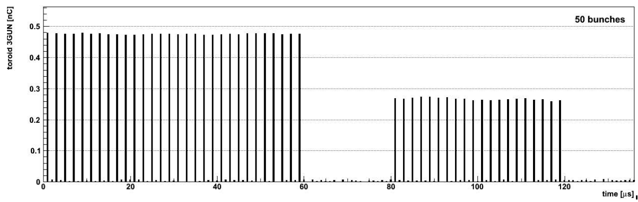

Figure 4: Two trains of bunches, generated by two injector lasers shifted in time.

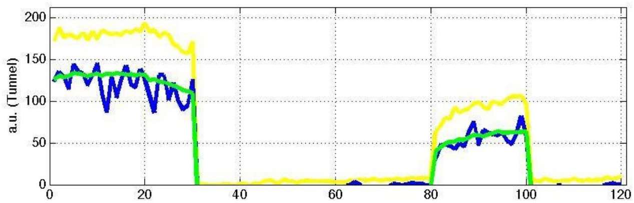

Figure 5: Lasing of two bunch trains with a factor of 2 difference in charge, e.g. of 0.5 nC for the first and 0.25 nC for the second bunch train. The horizontal scale is µs. The blue line indicates the actual SASE pulse energy produced by each individual electron bunch in the macro pulse. The green line is the time average of this signal. The yellow line indicated the maximum SASE level which occured since the measurement was started.

in bunch length was between first and second bunch train. However, the spectral measurements showed, that the wavelength of both bunch trains were the same within each others bandwidth.

Recently, first tests have been performed with FLASH1 and FLASH2 in operation. In Fig. 6, the spot of the FEL radiation produced in FLASH2 is shown [9]. While these tests were done, SASE was delivered in FLASH1 at the same time. This shows, that the fast kicker is working in combination with the DC-septum, the two injector lasers produce FEL radiation simultaneously in FLASH1 and FLASH2.

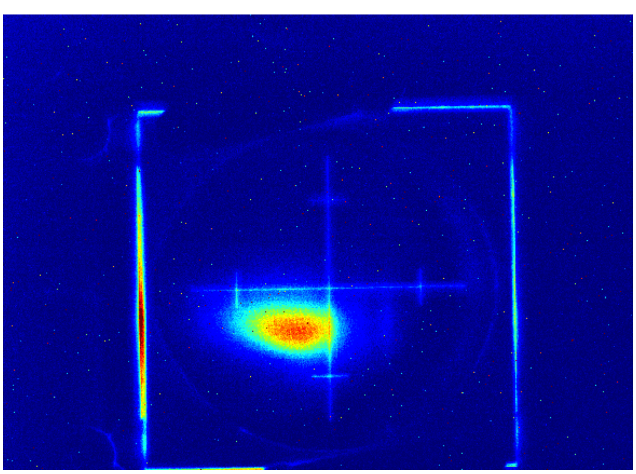

Figure 6: First Lasing at FLASH2. Shown is the spot on the YAG-screen.

SUMMARY AND OUTLOOK

Several tests have been performed to show that simultaneous operation of two beamlines is possible. After having shown that the fast kicker system can deliver bunch trains with a flattness and stability that does not influence the overall stability of FLASH and that also changes in RF-settings within an RF-pulse can be achieved that allow for different compression settings for different charges (and therefore different bunch lengths), it has now also been shown that we can get both bunches to radiate at the same wavelength.

The FLASH2 commissioning in 2014 has resulted in first lasing during the summer. The remainder of the year is dedicated to beam time showing that we can actually deliver this in two different beamlines.

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