COMMISSIONING OF THE FLASH2 ELECTRON BEAM DIAGNOSTICS IN RESPECT TO ITS USE AT THE EUROPEAN XFEL

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Abstract

This report presents the first operation experience of the electron beam diagnostics at FLASH2. FLASH2 is a new undulator line at the FLASH linac at DESY. Most electron beam diagnostics installed, like the beam loss monitors, cavity beam position monitors, toroids, beam halo monitors, have been designed for the European XFEL, and will provide operational experience beforehand. A few systems, as for example the button beam position monitors and the ionization chambers, have been developed for FLASH. The controls use the new MTCA.4 standard. Both linacs, FLASH and the European XFEL, require similar performance of the diagnostics systems. Many beam parameters are similar: bunch charge of 0.1 to 1 nC, pulse repetition frequency of 10 Hz, while others will be more critical at the XFEL than the ones currently used at FLASH, like the bunch frequency of up to 4.5 MHz. versus 1 MHz. The commissioning of FLASH2 and its diagnostics is ongoing. The beam monitors have accompanied the first beam through the linac, fine tuning for some systems is still to be done. The achieved performance will be presented in view of their use at the European XFEL.

INTRODUCTION

The FLASH linac at DESY, Hamburg has recently been upgraded with a second undulator beamline, FLASH2, in order to increase the number of user beamlines [1,2]. FLASH is a Free Electron Laser (FEL) based on Self Amplified Spontaneous Emission (SASE-FEL). It produces ultra-short, highly intense photon beams typically in the range from 45 down to 4.2 nm.

In order to make use of the synergies between the FLASH facility and the European X-ray Free Electron Laser (E-XFEL) [3], many of the diagnostics components installed in FLASH2 are the same or similar to the ones developed for the E-XFEL [4,5]. Some are similar to the old FLASH components, and others have been designed especially for FLASH2. This paper gives an overview of the diagnostics installed in FLASH2 and reports on the first operational experience.

Overview of the FLASH Linac

Figure 1 shows schematically the layout of FLASH. Two independent lasers are sent to the Cs_2Te cathode, placed on the back plane of the 1.5-cell RF-gun, to produce, within the same RF pulse, the beam for each of the two electron beamlines, FLASH1 and FLASH2. In the following FLASH will denote either the whole facility or the common, accelerating part.

The electron beam is accelerated to an energy of up to 1.25 GeV by 7 cryo-modules, each containing 8 TESLA cavities, operating at 1.3 GHz (in yellow in the figure). One third-harmonic cryo-module containing four 3.9 GHz cavities (in red), placed after the first 1.3 GHz module, is used to linearize the energy chirp. Two magnetic chicanes are used to compress the bunches, down to the order of 100 fs and below, in order to achieve the peak currents needed for the FEL process.

A kicker-septum system is used to extract part of the beam pulse into the FLASH2 line. The kicker rise time of ca. 30 µs determines the minimum gap between the beams for FLASH1 and FLASH2, which are within the same pulse. The electrons produce the FEL beam in FLASH1 within six 4.5 m long fixed-gap undulators. The photon wavelength is varied by changing the electron energy. A seeding experiment, sFLASH, is also placed in the FLASH1 beamline.

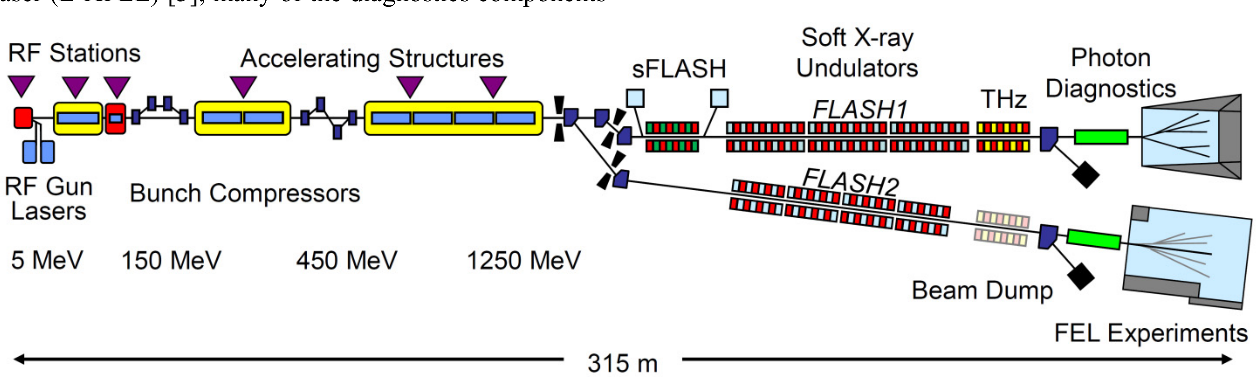

Figure 1: Schematic of the FLASH facility with the two undulator beamlines, FLASH1 and FLASH2 [1].

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ISBN 978-3-95450-141-0

Twelve 2.5 m long variable gap undulators are used to produce the FEL beam in FLASH2. In this way one can vary the wavelength of the photons produced independent of FLASH1. In addition also small differences of the acceleration gradient for pulses for the two beamlines can be provided if they are within the optics acceptance.

After each undulator beamline, the electrons are sent to a dump, while the photons pass a diagnostics section, followed by the user beamlines. On request THz radiation can be produced in a special undulator, placed after the SASE undulators in FLASH1. A similar undulator is planned to be installed in the FLASH2 beamline as well.

The construction of the new experimental hall has been finalized in spring 2014 and now the photon beamlines are under construction.

The European XFEL has similar requirements, using the same type of accelerating cavities, gun, pulse structure, controls etc. Table 1 lists some main design parameters for the E-XFEL and typical operational parameters for FLASH. Most E-XFEL components will have to deal with a bunch frequency of up to 4.5 MHz, as compared to currently a maximum value of 1 MHz at FLASH. While FLASH has been designed for bunch charges of 1 nC and higher, and runs usually with charges well above 100 pC, the XFEL operation is specified for 0.1 to 1 nC, but precautions have been taken, that the diagnostics is also capable to work at charges down to 20 pC.

Table 1: Typical Parameters of the E-XFEL and FLASH

Parameter	E-XFEL	FLASH
Max. energy [GeV]	17.5	1.25
Pulse repetition rate [Hz]	10 (25**)	10*
Max. bunch frequency [MHz]	4.5	1
Max. pulse duration [µm]	600	800
Bunch charge [nC]	0.1 - 1	0.1 - 1
Photon wavelength [nm]	0.05 – 6	4.2 - 45

* FLASH2 operates often at 1 Hz to reduce activation

** The RF should able to work at 25 Hz with reduced gradient

DIAGNOSTICS OVERVIEW

As mentioned before, many diagnostic systems installed in FLASH2 have been designed for the European E-XFEL, whose electron gun has recently started commissioning. Some components have been designed for FLASH2, but are based on similar concepts, e.g. same type of electronics crates and timing system. Therefore the experience gained by commissioning and operating these systems in FLASH will be a great benefit for the E-XFEL operation. It is expected to contribute to a faster commissioning of these components in the larger linac and may help for a better performance. The beam time for commissioning and machine studies at the E-XFEL will be limited, and some more restrictions on beam conditions apply. At FLASH these conditions are somewhat more relaxed.

Table 2 gives a brief overview of the diagnostics systems and numbers installed in FLASH2 in comparison to the number of (same or similar) components to be installed in the E-XFEL. There are toroids, used for measuring the charge, screen stations, beam position monitors (BPMs) of various types, beam loss monitors (BLMs), and beam halo monitors (BHMs). Other monitors present in both linacs belonging to the so-called special diagnostics, as for example the bunch compression monitors and the beam arrival time monitor, are not discussed in this paper. In addition to the diagnostic item used for both machines, additional types will be installed in the E-XFEL only, such as the wire scanners and dosimeters, and some diagnostics of the same type, but with different geometry and aperture, as for example cavity BPMs with 40.5 mm aperture. Other systems installed in FLASH2, like the ionization chambers in the dump area, the Cherenkov fibers along the undulator section, are not present in the E-XFEL and are not shown in the table either. The apertures given in the table are true for components which are identical or very similar in both linacs (vacuum part and electronics). More details on each type of component are given later in the paper.

Table 2: Number of Standard Diagnostics Components in the E-XFEL and FLASH2 (similar components installed in FLASH1 are also counted).

Monitor Type	Aperture [mm]	E-XFEL	FLASH2	FLASH1
Toroid	40.5, 44, 100	36	5	
Screen station	40.5, 100	64	7	
Screen on dump window		3	1	
Cavity BPM	10	101	17	3#
Button BPM*	10 - 100	>300	12	4
Stripline BPM*	34, 44	-	4	
BLM	-	>300	~56	
BHM	100	4	1	1

\# Cavity BPMs installed in FLASH1 for tests

* Different electronics, based on the same principle, in FLASH2 (designed at DESY) and the E-XFEL (design at PSI)

General Characteristics

We mention here a few common characteristics for most new diagnostic systems: They deliver bunch by bunch measurements and are designed for lower charge than the older FLASH components, well below 1 nC.

The two photo-injector lasers can deliver bunch trains with different bunch number, repetition frequency and bunch charge for the two beamlines within the same RF pulse. Figure 2 shows an example of a possible pulse

ISBN 978-3-95450-141-0

structure. A gap between the two parts of the train of at least 30 µs is needed for the rise time of the kicker. While the diagnostics should deliver a measurement for both trains, they do not have to give optimal performance for both.

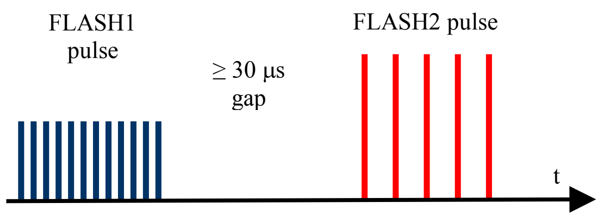

Figure 2: Example of different pulse structures and bunch charges within a FLASH bunch train for the FLASH1 and FLASH2 undulator beamlines.

A new timing system [6] and the E-XFEL type machine protection system [7] deliver the necessary flexibility for the operation of two beamlines.

The electronics is, in general, based on the MTCA.4 technology [8]. This has the advantage of having a modular architecture, redundant power, well defined management, high availability. On the other hand it's a rather new technology, this bringing some challenges with it: there is lack of experience and some components are still being optimized. Nine MTCA crates have been installed for diagnostics at FLASH2, and several others at FLASH and FLASH1.

All electronics in FLASH2 is installed in a technical corridor which is parallel to the accelerator tunnel. The situation will be different in the 2 km long E-XFEL tunnels, where the electronics has to be installed in racks inside the accelerator tunnel. This situation requires very reliable and remotely manageable systems, since maintenance is restricted to scheduled accesses or will cause downtime of the facility.

Diagnostics Commissioning

When talking about the commissioning of the components of an accelerator, one usually thinks of the last step: the commissioning with beam. However at least as important is the sometimes called "cold" commissioning, i.e. the work being made previously to the first beam through that component:

- Check the monitors (mostly the vacuum parts): visual and electrical check of components, short, symmetry etc.;
- Check cables: sometimes damage occurs after installation;
- Check and preliminary set up of electronics: check individual components (in many cases MTCA-components) and how they work together; check availability and quality of signals, like timing, IT; use test pulses;
- Test servers;
- Make sure operating panels are made and working;
- Pre-calibrate components with values from theory or laboratory measurements.

More than one time we discovered that one or more components were not available or accessible due to e.g. connection problems or server limitations. It is probably unavoidable that some problems occur, but through careful preparation one can reduce such cases.

The initial commissioning with beam is made in parallel with the commissioning of the accelerator. That is when the electronics settings and timing are roughly adjusted, in order to search for first beam signals. Later the fine adjustment is made, often during dedicated beam time.

First Beam in FLASH2

All main diagnostics components were available for the first beam attempt in FLASH2 on March 4. Even if not all were in the foreseen state yet, all were able to evaluate the beam charge, position, transverse profile and losses.

Figure 3 shows a photo of the first part of the FLASH2 extraction region. Part of the septum can be seen in the bottom of the picture. One notices the small separation of the two beamlines. About 4 m after the septum one can see the optics box of the first screen station in FLASH2. This is followed by a toroid, which is just in front of a sextupole (in yellow). In front of the screen there is a stripline BPM mounted in a quadrupole. BLMs are distributed along the beamline (cannot be seen in the figure). These are the diagnostics elements that played a major role during the first operation looking for beam.

Figure 3: First part of the FLASH2 extraction beamline (right) together with part of the FLASH1 beamline (left).

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The work started with carefully setting the linac parameters in order to have stable SASE radiation in FLASH1 from two bunches, each generated by one of the injector lasers. The beam energy was about 700 MeV. Then the kicker was switched on to separate the two bunches in front of the septum by about 20 mm (corresponding to a kick of 2.2 mrad), as theoretically required for injection into FLASH2. Figure 4 shows two bunches on the screen at the septum entrance. The central one is for FLASH1, and the upper one to be extracted into FLASH2.

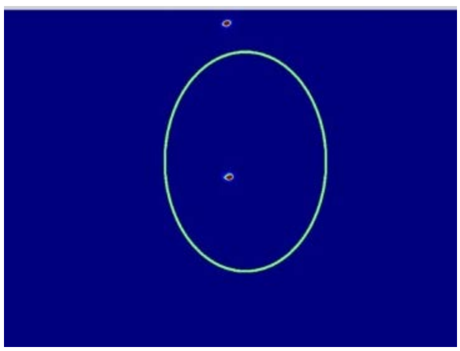

Figure 4: Two beam spots, for FLASH1 (center) and FLASH2 (up), separated by about 20 mm, are seen on the screen before the septum.

After the screen has been removed, and after some steering was applied, beam losses were seen by the first BLMs in FLASH2. Figure 5 shows the raw signal from a BLM about 6 m after the separation. The signal at 780 µs is caused by the FLASH2 bunch, the one at 700 µs are losses from the first bunch continuing its path in FLASH1 (seen here due to the small geometrical separation). One notices also a plateau in the losses, which is caused by the dark current kicked into the FLASH2 beamline.

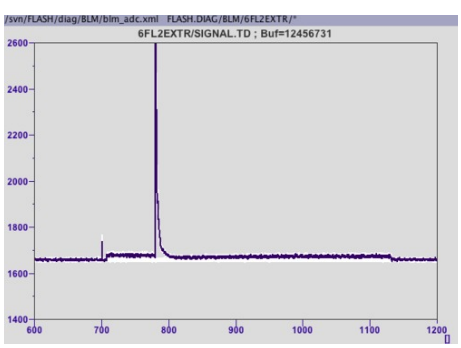

Figure 5: Raw BLM signal from a BLM at 6 m into the FLASH2 extraction. The horizontal axis is time in µs, the vertical one is in arbitrary units.

While BLM signals show that the beam is nearby, it's not clear if the beam was transported in the FLASH2 beamline, or just lost at the beginning. The first BPM (Figure 6a) and the first toroid (Figure 6b), at 4 m inside FLASH2, showed that indeed there was beam at this location. The raw BPM signals are measured by an oscilloscope. On each curve, the signals from two opposite pickups are displayed, one of them being delayed by an additional cable. The beam was roughly centered on the BPM.

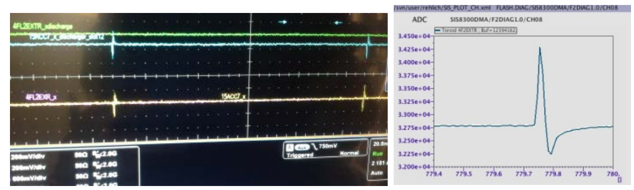

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Figure 6: Signals from the first BPM (a) and toroid (b) in FLASH2. a: The yellow (lowest) and blue (middle) curves on the scope show each the two signals from two opposite pick-ups of the BPM at 4 m; b: Raw toroid signal from an ADC.

The screen nearby (see Figure 3) was inserted in the chamber and after some adjustments the image was visible on this screen (Figure 7).

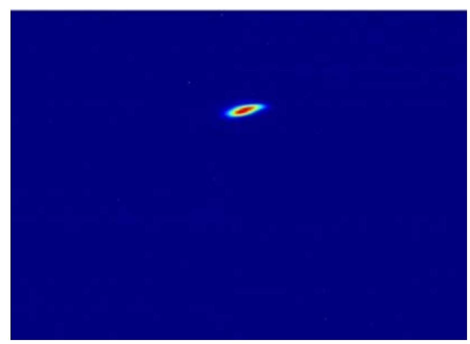

Figure 7: First beam seen on the first screen in the FLASH2 beamline.

While the first beam at the beginning of the FLASH2 beamline was obtained very quickly, it was impossible to get it much further downstream during this first beam time. Later it became clear that a collimator was blocking the beam path, due to some missing connection in the control system. During the following allocated beam times one was able to go further and further into the beamline, so that on May 23 the beam could be transported to the dump. Parallel operation of the two beamlines has meanwhile become routine.

The following sections describe each diagnostic system.

CHARGE MONITORS

The charge monitoring is based on AC current transformers, called toroids, developed at DESY and used in all accelerators on site. In Figure 8 one can see a ceramic gap (a) in FLASH2, over which the transformer housing, or toroid body, is mounted (b). The body is made of two halves so that it can be installed without breaking the vacuum.

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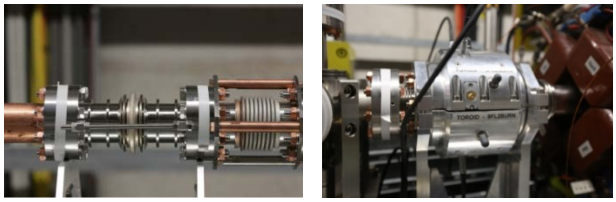

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Figure 8: Toroid installed in FLASH2: ceramic gap (a) and toroid (b).

A MTCA-based readout system, containing front-end and back-end electronics, has been designed for the E-XFEL and FLASH and is now under test [9]. The front-end electronics contains a signal combiner, a filter and an amplifier and will be placed close to the toroid. The back-end electronics will be placed in the MTCA-crate and contains a rear transition module (RTM) in combination with a SIS8300 digitizer [10]. This system will offer a high dynamic range and high sensitivity, and includes a test pulse generator for remote testing of the entire signal chain.

Until the E-XFEL system is ready to be installed, an intermediate solution was adopted for all 5 toroids of FLASH2 (see Figure 9). The signals from the 4 toroid pickups are summed up. A preliminary version of the front-end electronics has been installed close to the pickups in the tunnel. CAT cables bring the differential signals to the MTCA crate.

So-called adapter RTMs convert the differential signal to a single ended signal, that is delivered to the ADC, which accepts amplitudes of ±1 V. From here, the signals go to the SIS8900 RTM, which passes the signal to a SIS8300 ADC card [10], in the same slot of the MTCA crate. The sampling rate is 108.3 MHz.

Two toroids in FLASH have also been equipped with the new electronics. With this system a resolution below 1 pC rms has been measured, while the FLASH systems have a resolution around 3 pC.

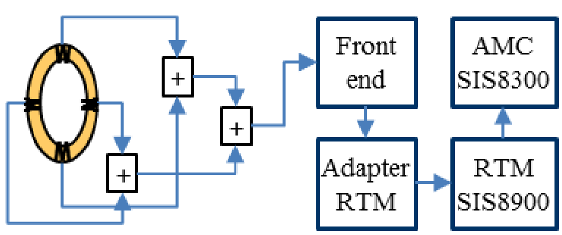

Figure 9: Schematics of the toroid system at FLASH2.

Figure 10 shows a typical raw signal from a toroid in FLASH2. For the moment the signal processing is made in the server. This integrates typically 4-5 points along the signal (between the red lines) and subtracts the base line (evaluated over 4-5 samples, between the yellow lines). Later the processing will be made in the FPGA.

The result of the integration procedure proved to be quite insensitive (to % level) to changes in the sampling point of the order a couple of ns [11]. However, in order to improve even further, it is intended to implement in the final system an automatic correction procedure to optimize the timing of ADC and signal [9].

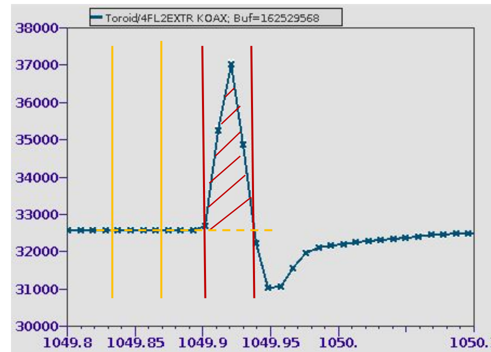

Figure 10: Example of raw toroid signal.

The charge readings are an important part of the machine protection system. A transmission interlock is planned as for the E-XFEL [9]. For the time being, as a temporary solution, the Toroid Protection System (TPS) system developed for FLASH is used [12]. Each of three modules compare the (analogue) signals from a pairs of toroids, one at the beginning and the other at the end of each linac section: FLASH (the common part), FLASH1, and FLASH2. Each TPS module generates an alarm when the difference of single bunch signals or the integrated charge loss is higher than a threshold value. Also a low charge alarm is send when a bunch is expected, but no charge, or too low charge is measured.

This system configuration however has a gap in the septum region, where the machine protection relies only on the beam loss monitors. This gap will be closed as soon as the E-XFEL system becomes available. This system will be able to deal with the distribution of beam into several branches.

SCREENS

The screens are an essential component for the beam characterization and tuning. For the E-XFEL and FLASH a resolution of 10 µm over the entire field of view is required. One concern when designing the screens was avoiding coherent optical transition radiation (COTR) first observed with ultra-short bunches at LCLS [13]. Based on a series of tests with various scintillating materials, LYSO:Ce screens with a thickness of 200 µm were chosen [14].

Figure 11a shows the layout of the screen system, composed of vacuum chamber, mover and optic box. The beam image created by luminescence on the screen, which is mounted perpendicular to the beam axis, is observed under 45 deg. Potential COTR radiation is reflected back into the beam pipe and thus is geometrically suppressed. In addition to the scintillator, a calibration target is also installed in the system and can be moved into the field of view. A CCD camera is used for visualization. In order to extend the depth of field, the Scheimpflug principle is used. An installed station in FLASH2 is also shown in Figure 11b.

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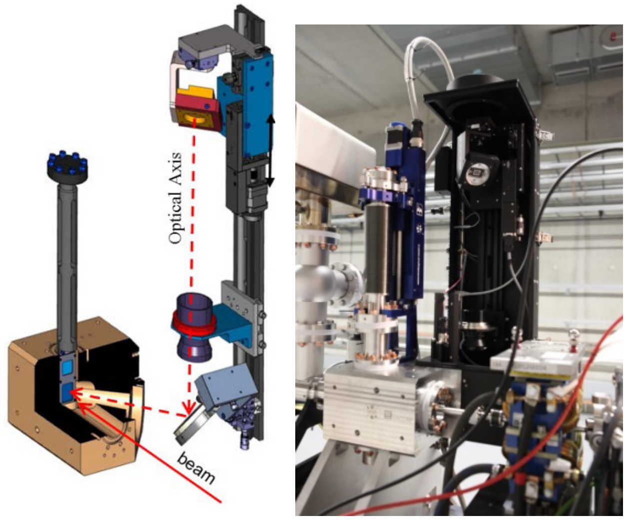

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Figure 11: Layout of a screen system (a) and installed station (b) in FLASH2.

Laboratory tests gave a resolution of 5.4 µm, which is well within the requirement. Two versions are installed in FLASH: most of the stations have an optical magnification of 1:1 while the stations requiring a large field have a magnification of 1:2.

Figure 4 shows the two beams, in the center for FLASH1 and the upper one for FLASH2 on a screen with wide field of view, just before the septum. The separation between the two beams is about 2 cm. Another screen of the same type, with a beam chamber of 100 mm diameter has been installed in the dump line.

In Figure 7 one can see the beam observed for the first time on the first, standard screen in FLASH2, in the extraction region, with a magnification of 1:1.

A special luminescent screen, a Chromox ceramic with a thickness of 1 mm, is placed at the dump vacuum window [15]. An optical system looks at the screen through a special port placed upstream. After commissioning it is expected that this system delivers constantly an image of the beam at the dump.

BUNCH POSITION MONITORS

Cavity BPMs (CBPM) have been installed in the undulator section. Button BPMs and several stripline BPMs have been installed in the remainder of the electron beamline.

Cavity BPMs

17 CBPMs, developed for the E-XFEL have been installed in the undulator section [16]. Figure 12a shows a CBPM installed in FLASH2. The monitors have a total length of 100 mm and an aperture of 10 mm. Each BPM has a dipole and a reference cavity, both with a resonant frequency of 3.3 GHz and a low quality factor of around 70. Due to the low Q it is possible to separate the signals of consecutive bunches, even at E-XFEL bunch repetition rates of 4.5 MHz. The monopole resonator is needed to normalize the charge, and to provide a phase reference to determine the beam offset sign. Two antennas are mounted for the horizontal signal and two for the vertical one in the dipole resonator, for symmetry reasons. Only one per plane is connected to a cable for readout, while the opposite pickup is terminated with a load. The reference cavity has one pickup for monitoring of the monopole signal.

The electronics has been built by PSI in a modular way [17,18]. Each Modular BPM Unit (MBU) contains up to 2 RF front ends (RFFE), each of these serving one cavity BPM (see Figure 12b). The RFFE mixes the 3.3 GHz signals from the pickups down to baseband. 16-bit 160 MS/s ADCs are used for the six I and Q signals. A digital signal processing board ("GPAC" board) is used for signal processing and interfacing with the control system. The interfacing to the DOOCS system is done using a FPGA-FPGA bridge between FPGAs located on the GPAC board and on a DAMC02 card [19] installed in a MTCA crate. Both crates are connected by optical fibers.

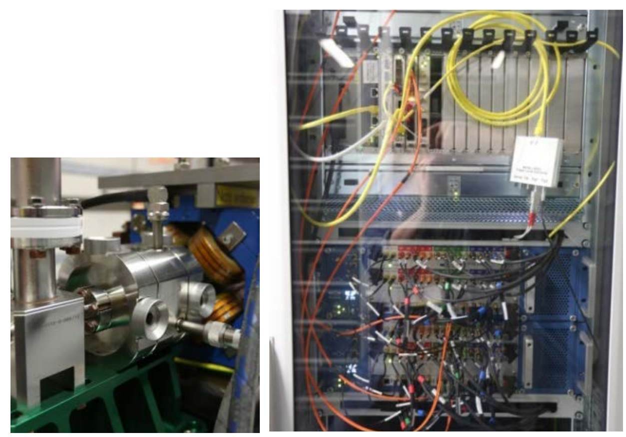

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Figure 12: CBPM installed in FLASH2 (a) and electronics rack (b) with 2 MBUs (lower crates) and a MTCA crate with DAMC02 card for the CBPMs.

Three further CBPMs of the E-XFEL prototype development have been installed in FLASH1 for tests. For a beam charge of 0.24 nC a resolution below 1 µm rms was measured even for a beam offset of 1 mm. This is well within the required resolution of 2 µm rms* for a beam offset between ±0.5 mm and charges above 0.1 nC, as specified for FLASH2.

The CBPMs deliver also a measurement of the bunch charge. The resolution measured at the FLASH1 CBPMs for a bunch charge of 0.24 nC is 0.13 pC.

Button and Stripline BPMs

Button BPMs with the E-XFEL aperture of 40.5 mm and with FLASH standard beam pipes of 34 mm, both with button feedthroughs of 16 mm diameter have also

* Note that the requirement at the XFEL is 1 µm rms, but was somewhat relaxed at FLASH since the cables are much longer, of maximum about 15 instead of 6 m, due to the placement of the electronics outside of the tunnel.

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been installed in FLASH2 (see Figure 13a). In addition at 3 locations in the undulator section, where space did not allow for installation of CBPMs, small, finger-like feedthroughs have been installed in the beam pipe, like the ones in the FLASH1 undulator section. Furthermore, 4 stripline BPMs installed inside quadrupoles yokes have been placed in FLASH2 [20].

A special electronics based on the MTCA standard has been designed for these both types of BPMs. This is called low charge BPM (LCBPM) electronics [21], in contrast to the old monitors in FLASH, designed for charges of 1 nC and higher.

The signals from two opposite BPM pickups are send through the same cable, one of them with a delay of 100 ns, to a RTM module (see Figure 13b). This pre-conditions the short signals, by filtering and using a peak detector, so that it is possible for an ADC to sample them. A cascade of amplifiers enables the fine tuning of the signal amplitude for best performance for each charge and beam offset range. The resulting signals are fanned out to 4 outputs for digitization.

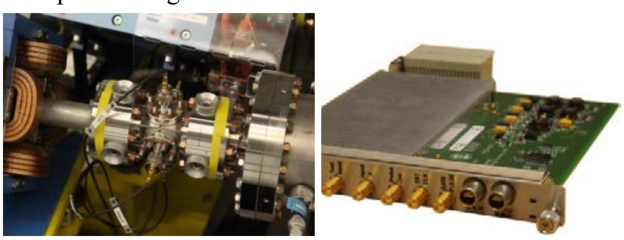

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Figure 13: Button BPM (a) and RTM card for button and stripline BPMs (b).

SIS8300 cards [10] are used for digitization and digital data processing. The electronics processes bunch by bunch data in an FPGA. Therefore it is suited to be used in low latency feedback and interlock systems.

Figure 14 shows the residuals measured for a stripline and a button BPM in FLASH2 for a bunch charge of 36 pC, measured over 200 pulses. A sigma of about 22 µm is obtained for the stripline, and about 40 µm for the button BPM is obtained.

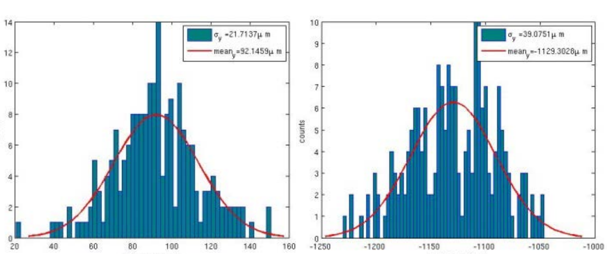

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Figure 14: Residuals of the BPM display for a stripline (a) and a button (b) BPM in FLASH2.

Note that due to the measurement principle the beam jitter is included in this number. Even with beam jitter included the values already are close to the specifications. A resolution of 30 µm rms is generally required from the BPMs in FLASH, apart from the undulator sections, while at the E-XFEL the requirement is in general 50 µm rms.

BEAM LOSS MONITORS

The beam loss monitor (BLM) system developed for the E-XFEL [22] is also installed at FLASH2. Figure 15 shows schematically one BLM unit. The electrons hitting the beam pipe produce secondary radiation which then passes through a scintillator, placed in a cylinder protecting against surrounding light. The rod is opto-mechanically interfaced to a photomultiplier (PMT). The high voltage (HV) of the order of hundreds of volts, needed to power the PMT is produced by a circular printed circuit board placed at its base. This is made with Cockcroft-Walton multipliers powered by an oscillator. The signal from the PMT is send to the readout electronics (RTM), which stretches the pulse and controls the HV. The signal is then digitized and sent to a DAMC02 board, where low latency digital data processing is done [19]. Part of the analogue signal is sent to comparators, to provide single bunch alarms with lowest possible latency. The digital data processing in the FPGA of the DAMC02 can generate one of the following alarms: single bunch alarm, when the signals of individual bunches pass a threshold; multi bunch alarm, when a certain number of bunches pass a threshold; and integration alarm, when the integral of the BLM signal has reached a threshold. The settings of the fast comparator signal path are also controlled by the FPGA. If either an analog or a digital alarm is generated, this is sent to the machine protection system (MPS). The latency of the BLM electronics is on the order of 100 ns.

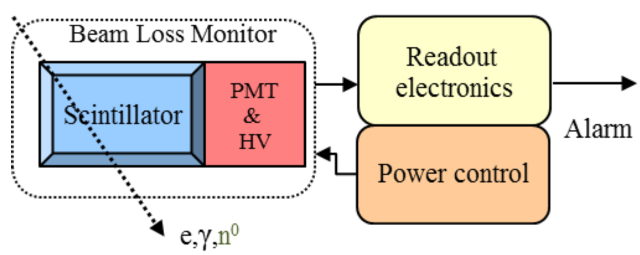
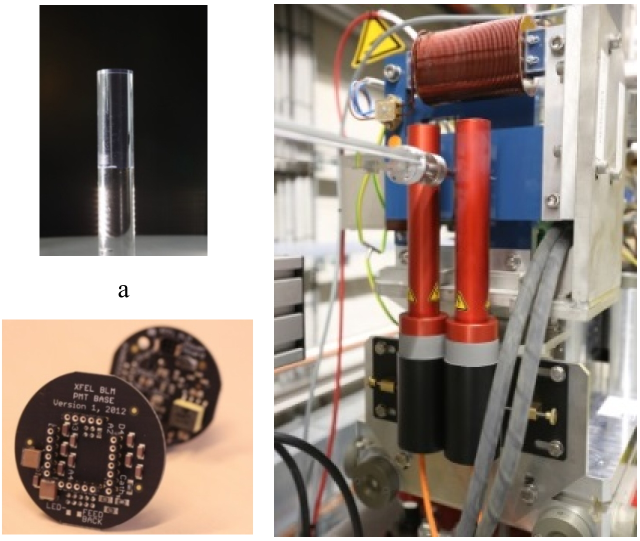


Figure 15: Schematic of a BLM unit.

Figure 16 shows a photo of a scintillating rod (a), of printed circuit boards (b) and of two BLMs mounted left and right of the beam pipe in the undulator section (c). A typical signal in the control system from a BLM is shown in Figure 5.

Note that in the septum area, both for FLASH1 and for FLASH2, the MPS relies only on the BLM system, therefore in this area particular care has to be taken.

ISBN 978-3-95450-141-0



a b c

Figure 16: Scintillating rod of a BLM (a), printed circuit boards mounted in the PMT housing (b), and two BLMs mounted in FLASH2.

Cherenkov Monitors

The permanent magnets of the undulators are sensitive to radiation and therefore they have to be protected. Complementary to the BLMs installed between the undulators, optical fibers are to be installed inside the vacuum chambers of the undulators, right and left from it [23]. The radiation produced by electrons hitting the beam pipe produces Cherenkov light which is collected by PMTs mounted at the upstream end of the fibers. This system is similar to the one in FLASH1, but with newly designed electronics. The system has not yet been commissioned. At FLASH1 it has proven to be very helpful in setting up the machine and reducing the overall losses. At the E-XFEL a different system, based on dosimeters has been adopted instead [24].

BEAM DUMP INSTRUMENTATION

Several types of monitors ensure that the high power electron beam is safely dumped. The part installed inside or around the vacuum pipe is the same as in FLASH1, while the electronics have been redesigned using the MTCA standard and using synergies to the E-XFEL BLM development.

Figure 17 shows the dump vacuum chamber. The beam coming towards the dump passes along the last 2 m before the vacuum window among 4 ionization chambers placed symmetrically in tubes around the beam pipe (with red caps in the figure). 4 fused silica fibers are installed next to them, in the same pipes (not in the figure). After passing the vacuum window, of which a part can be seen as well, the beam generates signals in the loops of a magnetic BPM and the sensors (placed under protecting caps) of a beam halo monitor.

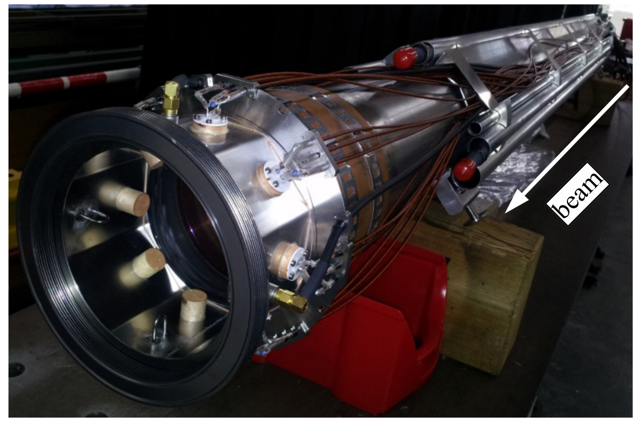


Figure 17: The dump vacuum chamber with pipes for BLM fibers and ionization chambers. At the closer end is the vacuum window. The caps of the beam halo sensors and the loops of the magnetic BPM placed after the vacuum window (in beam direction) can also be seen.

The individual systems are still under commissioning and are briefly described in the following.

Cherenkov BLMs

Four fused silica fibers are symmetrically installed along the last 2 m of the beamline [25]. These produce Cherenkov radiation, which is then coupled to PMTs and read out using the same electronics as for scintillator-based BLMs.

Ionization Chambers

Air filled Heliax cables are used as ionization chambers, like in FLASH1 [25]. They are installed next to the BLM fibers. Their downstream ends covered by red caps can be seen in Figure 17.

The electronics has a large dynamics range, from 10^{-4} to 10^{4} μA, like the one for FLASH1. The form factor has been adapted to MTCA standard, and the front end was placed on an RTM.

Such ionization chambers will not be used at the E-XFEL.

Beam Halo Monitor

Four pCVD diamond and four artificial monocrystalline sapphire sensors, placed inside protecting caps, constitute the beam halo monitor (BHM) [26] (see Figure 17 and Figure 18). It has the same design as the one in FLASH1. To avoid the risk of vacuum leaks due to additional feedthroughs in this difficult environment, it is placed after the vacuum window in a Nitrogen-flooded area. The sensors are operated as solid state ionization chambers and were proven in tests to be radiation hard.

The front-end signal shaping electronics is placed in the tunnel, close to the BHM. The signal is then bought to an RTM and DAMC02 card. The RTM and the firmware are quite similar to the ones for the BLMs.

ISBN 978-3-95450-141-0

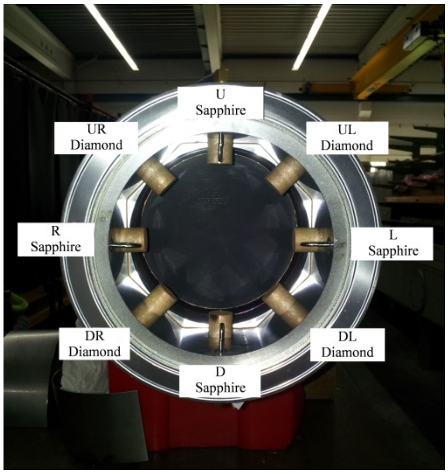


Figure 18: Diamond and sapphire sensors of the BHM placed in protecting caps.

Similar BHMs will be used also in the dumps of the E-XFEL, with the difference that the sensors will be placed outside of the beam pipe.

Magnetic BPM

Out of fear of vacuum leaks at the pickups, no BPM has been placed in the beam pipe closely before the dump window, but after it, next to the BHM sensors in an area is filled with dry Nitrogen [27]. In order to avoid signals from ions, it was decided to use the magnetic field of the bunches, sampled with wire loops for monitoring. The signals are read with the LCBPM electronics. Such a BPM will not be used in the E-XFEL.

OTHER DIAGNOSTICS

Monitors for longitudinal bunch diagnostics have also been built into the FLASH2 beamline and are here only listed: a beam arrival monitor [28], a bunch compression monitor [29], and a coherent transition radiation monitor [30]. These are yet to be commissioned. Similar monitors will be also built into the E-XFEL.

SUMMARY

Many beam monitors built in the new FLASH2 undulator beamline have been designed for the E-XFEL, some were specially designed for FLASH2 and some have been copied from similar older systems in FLASH. Some systems have been fully commissioned (like the screen stations), some are still under commissioning (like the BPMs) or have a temporary solution (toroid system).

In spite of lots of work remaining to be made, recently the first lasing was obtained in FLASH2 [1,31]. The electron beam energy was 680 MeV and the photon wavelength was 40 nm. FLASH1 was producing FEL radiation at the same time, with 250 bunches per pulse, at a wavelength of 13.5 nm.

Meanwhile routine operation of FLASH2 in parallel to FLASH1 has become routine [32]. The experience gained with E-XFEL systems at FLASH2 will surely contribute to a faster and easier commissioning of the European XFEL.

ACKNOWLEDGMENT

This paper is a brief summary of the work of many people from several institutes. We thank the many colleagues who gave input and made comments to this paper.

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