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UPGRADE AND STATUS OF STANDARD DIAGNOSTIC-SYSTEMS AT FLASH AND FLASHFORWARD

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Abstract

Electron beam diagnostics plays a crucial role in the precise and reliable generation of ultra-short high brilliance XUV and soft X-ray beams at the Free Electron Laser in Hamburg (FLASH). Most diagnostic systems monitor each of up to typically 600 bunches per beam, with a frequency of up to 1 MHz, a typical charge between 0.1 and 1 nC and an energy of 350 to 1250 MeV.

The diagnostic monitors have recently undergone a major upgrade. This process started several years ago with the development of monitors fulfilling the requirements of the European XFEL and of the FLASH2 undulator beamline and it continued with their installation and commissioning. Later they have been further improved and an upgrade was made in the old part of the linac. Also the FLASHForward plasma-wakefield acceleration experiment has been installed in the third beamline.

This paper will give an overview of the upgrade of the BPM, Toroid and BLM systems, pointing out to their improved performance. Other systems underwent a partial upgrade, mainly by having their VME-based ADCs replaced with MTCA type. The overall status of the diagnostic will be reviewed.

INTRODUCTION

FLASH [1] is self-amplified spontaneous-emission free electron laser (SASE-FEL) user facility. It generates high brilliance ultra-short XUV and soft X-ray pulses. It is also a test facility for various studies.

Figure 1 shows a schematic drawing of the facility. Seven TESLA accelerating modules accelerate the beam to an energy of 350 to 1250 MeV. Within each bunch train with a length of typically 400-600 µs different lasers generate the sub-trains destined to the various beamlines. These can have different bunch frequency, up to 1 MHz, and bunch charge, typically between 0.1 and 1 nC. The train repetition rate is 10 Hz. During machine setup or special bunches may have a reduced rate of 1 Hz.

While the first 2 beamlines, FLASH1 and FLASH2, generate intense photon pulses for users, a plasma experiment, FLASHForward, was recently installed in the third beamline [2].

The FEL requires a precise control of the beam. The diagnostics system is essential for this, and therefore has to follow the increasing requirements over time.

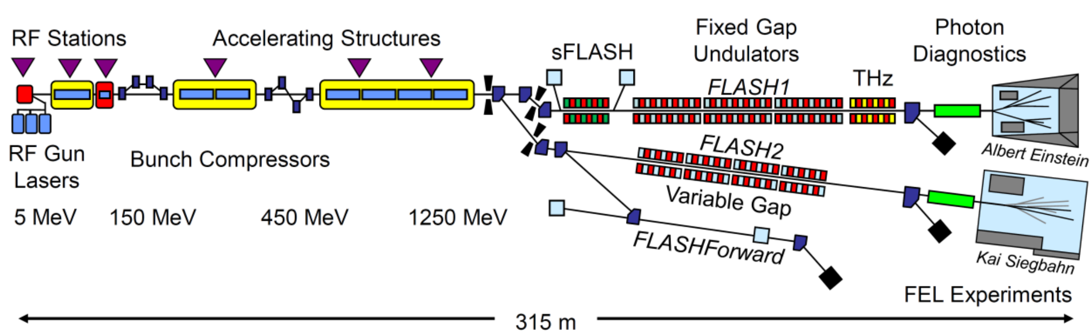

Figure 1: Schematic view of the FLASH facility [1].

This paper describes the recent upgrades that the various diagnostics systems underwent. After an overview of the diagnostics, the monitor types which underwent main upgrades are described, followed by the smaller work. The paper ends with a summary.

Standard Diagnostics at FLASH

Many different kinds of diagnostics have been installed along the years in FLASH: toroids to monitor the individual bunch charge, beam position monitors (BPM) of various kinds, beam loss monitors (BLM), beam size monitors, mainly OTR stations and wire scanners, dark current monitor etc. So-called special diagnostics has been developed mainly for longitudinal diagnostics, and is not the topic of this paper. Many of the systems deliver bunch-by-bunch information, and have to deal with the different bunch charge and pulse structure of the sub-trains for the various beamlines.

In recent years, many diagnostics systems have been developed for and installed in the European XFEL [3] and FLASH2 [4], which fulfil new requirements. The MTCA.4 standard [5] has been introduced for several systems. Besides the diagnostics, also LLRF and the timing system are based on this standard. Different systems

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share crates and processing (CPU) resources, power supplies and remote management capabilities. This makes their maintenance easier, as failure detection and solving is spread over several systems and groups within the institute and abroad. Synergies in the form of hard- and firmware development can also be shared by different systems.

Since their installation in FLASH2, the newly developed diagnostics systems have been further improved and also installed and commissioned in the E-XFEL and FLASHForward. Some of the diagnostics in the old common and FLASH1 beamlines have been also fully or partially upgraded. The changes in the various standard diagnostics systems at FLASH as well as the status of the other monitors are reviewed in the next sections.

Table 1 gives an overview of the main standard diagnostics monitors in FLASH. The current status of the electronics is shown, including the most recent upgrades.

Table 1: Overview of Main Standard Diagnostics Systems at FLASH and Their Electronics Type

System	**Electronics Type**	**#**
Toroids	E-XFEL	19
Button BPM	FLASH	39
Stripline BPM	FLASH	34
Magnetic BPMs	FLASH	2
Cold cavity BPMs	TTF2	6
Cavity BPMs	E-XFEL	21
Screen stations	E-XFEL/TTF2	12/20
Wire Scanners	TTF2	7
BLMs	E-XFEL	162
Beam Halo Monitors	E-XFEL	2

UPGRADED DIAGNOSTICS SYSTEMS

After the initial developments made for the E-XFEL and FLASH2 and their initial commissioning [4], many diagnostics systems have been further developed or improved.

While no standard diagnostics system has been fully exchanged, particularly the vacuum system remaining in general the same, major parts have been replaced for some monitor types. Particularly in the old FLASH1 and common beamlines, the old, VME-based systems, often named TTF2-type, have been replaced with MTCA ones, in order to eliminate some outdated monitors, and to have a unified system in the whole facility. Also, new systems have been installed in FLASHForward. The main upgrade work took place in the summer and winter of 2017.

Toroid Upgrade

Toroids, which are AC current transformers, are used for single bunch charge measurement [6]. The front end electronics and the MTCA Rear Transition Module (RTM) filters and dynamically amplifies the induced signal, before sending it to a SIS8300-L2D digitizer [7]. The system offers a high dynamic range, from ca. 0.2 pC to 2 nC.

This system has been installed in all beamlines, replacing the TTF2-type electronics, as well as the temporary solution initially installed at FLASH2 [4]. Figure 2 shows the resolution measured for the first bunch of the train for the FLASH1 and FLASH2 beamlines using a correlation method [8]. The bunch charge was 350 pC in FLASH1 and 60 pC in FLASH2. In both cases the resolution is ca. 0.2 pC rms. The second toroid still runs with the TTF2-type electronics, having a much higher noise.

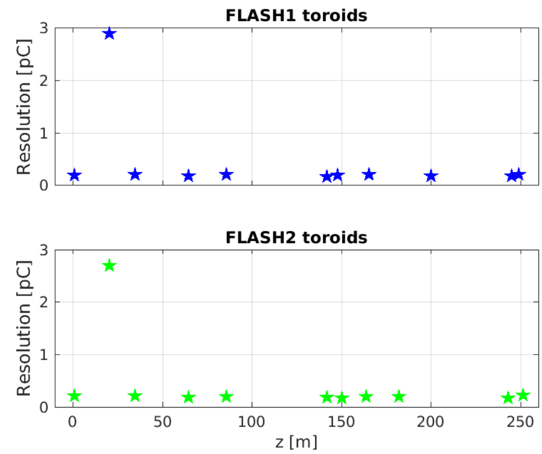

Figure 2: Toroid resolution in the FLASH1 (350 pC) and FLASH2 (60 pC).

In addition, the toroids are also used for transmission interlock. For this they compare the charge of pairs of toroids for the bunch train for each beamline. They monitor charge loses in individual bunches as well as in the integrated charge per train. Fast alarms are forwarded to the machine protection system (MPS). This function has replaced the old toroid protection system [9], which was designed for single beamlines.

For machine setup the toroid system implements a basic pulse detection (with lower accuracy) until the sampling phase is set correctly by the user. Once the toroids are configured in timing mode (full accuracy of ~0.2 pC, as seen in Figure 2) the system is able to detect gun-laser phase changes.

Stripline and Button BPM Upgrade

Most of the BPMs installed in FLASH are of stripline and button type. The initial VME-based TTF2 electronics has been developed for bunch charges of 1-3 nC. With the development of the FEL facility and the need for shorter and shorter bunches, the typical charge has been reduced to the order of hundreds of pC and lower. Therefore a new MTCA-based electronics has been developed and installed in the FLASH2 undulator beamline [10]. The signals from 2 opposite pickups are send on the same cable after each other with the help of a delay line. The 4 signals from each monitor are thus fed to 2 channels of a RTM.

The electronics was substantially improved since (Figure 3) [11]. Two BPMs (4 channels) can be connected now to one RTM. The firmware automatically adjusts itself to the signal peak. Other improvements include the

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addition of on-board test circuit, the improvement of the sensitivity, of the signal integrity and channel separation, and the addition of the capability to externally discharge the peak detectors. The magnetic BPMs [12] installed after the dump vacuum window, are equipped with the same system. The same RTM is used also for the so-called energy BPMs at the E-XFEL, which consist of button arrays installed in the flat bunch compressor chambers.

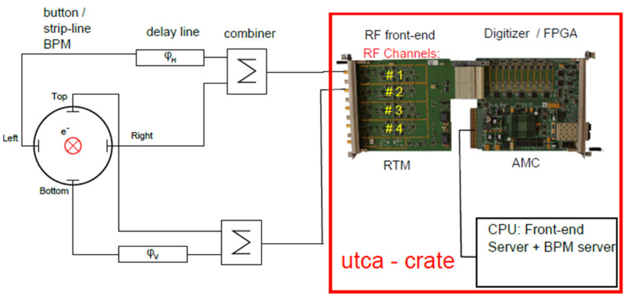

Figure 3: Upgraded stripline and button BPM electronics.

The performance has been evaluated with beam and compared to the old VME system. The charge range has been extended towards low charges, coming close to 10 pC. The resolution has been improved by ca. a factor 10 [11].

BLM Upgrade

A MTCA-based system has been developed also for the BLM and BHM systems at the E-XFEL and FLASH [13,14].

Figure 4 shows the main parts of a BLM. The light produced by lost electrons or induced photons in the scintillators is send to a photo-multiplier (PMT). The high voltage is produced locally in the detector front-end, which also pre-processes the signal which is then sent to an RTM connected to a DAMC2 [15].

While this system was installed initially in FLASH2, it is now installed in all 3 beamlines. In a few cases the old scintillators have been re-used, namely the ca. 2m long scintillator ‘paddles’ placed along the undulators in FLASH1.

Recent changes in the system include the so-called “LOLA masking”, for “special bunches”, distributed by the timing system. The BLM system marks these bunches which are rotated by a transverse deflecting structure and kicked to a special screen for longitudinal bunch profile monitoring, causing losses. As these losses should not cause cuts of the beam by the MPS, the BLM signal processing firmware ignores alarms at these bunch positions. The Beam Halo Monitors (BHM) [16], based on diamond and sapphire sensors, installed after the dump vacuum window at the end of each undulator beamline in FLASH1 and FLASH2, have meanwhile also been equipped with the same MTCA electronics as the BLMs. Only a small box including the HV generation and signal matching was specially developed to connect the BHMs to BLM electronics.

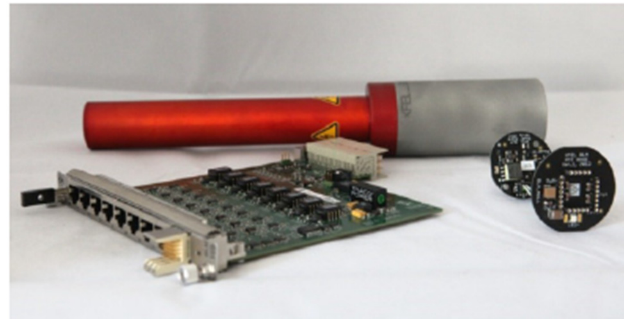

Figure 4: BLM detector with PMT, RTM and PMT base and high voltage generator.

Other Upgraded Monitors

For several systems only the ADC reading has been upgraded to MTCA type in the summer 2018. The old VME-ADCs, which due to their age needed more and more maintenance work, has been replaced with SIS8300 [7]. This is the case for the cold cavity BPMs, the Faraday cups in the gun section and the ionization chamber briefly described in the following paragraphs. This exchange is relatively uncritical, presuming a re-installation of basically the same servers and re-calibration.

Cold cavity BPMs [17] are installed in the first 6 TESLA modules. These BPMs have been developed more than 20 years ago. They consist of a resonator working at 1.5 GHz and a I/Q mixer based electronics. For two accelerating modules planned to be exchanged, XFEL-type button BPMs are going to be installed. For the remaining cold cavity BPMs, a new electronics development is planned.

Also based on resonances induced in a resonator, the Dark Current Monitor (DCM or DaMon) [18] enables a non-destructive measurement of the dark current, mainly produced by the electron gun. It also delivers an additional monitor of the bunch charge.

Air filled Heliax cables are used as ionization chambers [19]. They are installed along the last 2 m of the beampipe, before the dump window.

Also the ADCs of the Higher Order Mode (HOM) based beam monitors installed at 1.3 GHz TESLA accelerating cavities [20,21] will be replaced with MTCA. They are used for beam alignment and position monitoring. The HOM-electronics for the 3.9 GHz cavities [22] already uses SIS8300 ADCs.

STATUS OF OTHER MONITORS

In FLASH2 and FLASHForward screen stations developed for the E-XFEL have been installed [23,24]. They used LYSO:Ce screens mounted perpendicular to the beam axis. The light is observed under 45deg in order to suppress potential COTR radiation. The older OTR-screen stations in the common and FLASH1 beamlines [25] are based on 45deg CeYAG screens. It is planned to exchange them with the E-XFEL type on the occasion of a future major upgrade.

The CERN type of wire scanners [26] have been deactivated due to their old age and increased level of mainte-

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nance required. Another reason for this is the presence of screens at most locations where wire scanners are present. A replacement with XFEL type is being considered, in conjunction with the upgrade of the screen system. While also outdated, major maintenance work has been made on the so-called Zeuthen wire scanners [27] in the FLASH1 undulators, both in terms of hardware and small updates in the server. These scanners enable the matching of the beam in the undulator section. Their disassembly is planned in the process of replacing the undulators with variable gap ones.

Cavity BPMs, as developed for the E-XFEL have been installed in FLASH2 and FLASHForward [28]. They contain two resonators one monitoring a dipole mode for beam offset determination, the other a monopole mode, for charge normalization. Two types have been installed: for a beam pipe of 10 mm and respectively 40.5 mm in diameter. A resolution below 1 µm rms has been observed in most cavity BPMs.

Figure 5: Cavity BPM in the FLASHForward beamline.

Last but not least are the Cherenkov fibres [29] installed at either side of both main undulator sections. They help reduce the losses in the permanent magnets of the undulators, which can cause magnetization loss. Not mentioned here are longitudinal profile monitors.

SUMMARY AND OUTLOOK

Several diagnostics types have been developed for the E-XFEL and FLASH2, most based on the MTCA technology. Some of these monitors underwent further development and improvement. Further monitors have been installed at the new third beamline, hosting FLASHForward, while the old VME-based monitors in the old part of the linac have been partially replaced with the new system. The most significant changes were made in the button and stripline BPMs, the toroid and BLMs. Other systems underwent more minor changes, like the ADC upgrade for the cold cavity BPMs, ionization chambers and Faraday cups, while others were kept in the original state, like the cavity BPMs, the screen stations and the Cherenkov monitors.

Possible scenarios for future upgrades at FLASH are currently under investigation [30]. These will make upgrade work on the diagnostics system necessary, such as the replacement of the screen and wire scanner stations either with the E-XFEL type or with new design.

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