HIGH RESOLUTION AND LOW CHARGE BUTTON AND STRIP-LINE BEAM POSITION MONITOR ELECTRONICS UPGRADE AT FLASH

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Abstract

Historically the FLASH (Free Electron Laser in Hamburg) facility at DESY (Deutsches Elektronen-Synchrotron) in Germany has foreseen operation in a charge range from 1 nC-3 nC for which a VME based BPM (Beam Position Monitor) system has been in operation since 2005 with a later upgrade to lower charges. In the past few years the standard machine operation settled at a few hundreds of pC with a tendency to smaller charges down to 100 pC and less. The performance of the BPM system at charges below 300 pC was in many locations along the machine unsatisfactory, making the operation of the linac more unstable and less reliable. Therefore a new BPM electronic system based on the utca (Micro Telecommunication Computing Architecture) for physics MTCA.4 standard has been developed to overcome the limitations of the old electronics and has already been successfully in operation in FLASH 2. A substantially improved version of the RF (radio frequency) front-end and digital electronics/firmware has been developed in 2016 and tested successfully. The peak detector electronics have been extended to a double peak detection in four channels and the fully customized Firmware is working machine synchronous. In summer 2017 all old button and strip-line BPM electronics have been replaced with the new type. This paper summarizes the features and performance of the new BPM system, compares the beam jitter free resolution of the old and new BPM system and highlights its high single shot resolution of better than 10 μm rms at a charge of 15 pC.

OVERVIEW OF FLASH

Since 2005 the FLASH (Free Electron Laser in Hamburg, Germany) facility delivers FEL pulses in the soft X-ray regime to the photon science user community [1, 2]. The super conducting acceleration modules allow the acceleration of electron bunches within an RF pulse of 800 μs. The electrons are generated by a UV (ultra violet) photo injector laser which releases electrons from a cathode inside an RF (radio frequency) gun. The bunch repetition rate of up to 1 MHz at which the electrons are generated deliver up to 800 bunches inside the RF pulse. The electron beam is accelerated to an energy of up to 1.2 GeV after which it is fed to an undulator line to generate FEL pulses through the SASE (Self Amplified Spontaneous Emission) process. In 2014 the facility has been extended by a separate undulator line namely FLASH2 which is served by a separate laser system. A part of the electron bunch train can be kicked here for simultaneous and independent operation at a different charge and also a different FEL pulse wavelength [3]. This part from the bunch train can also deliver beam to the FLASHForward beamline where plasma wakefield experiments are planned for the near future. An overview of the entire facility can be seen in Fig. 1.

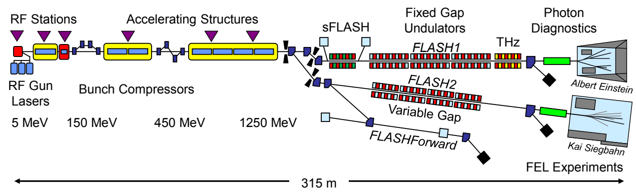

Figure 1: Layout of the FLASH facility.

It has been shown that the generation of FEL pulses on the order of few fs depends crucially on the charge of the beam [4, 5]. Newly developed electronics for LCLS (Linac Coherent Light Source) and the E-XFEL (European X-Ray Free Electron Laser) have already been operated and tested for low charge operation [6, 7]. Since the VME based BPM (Beam Position Monitor) installed at FLASH did not have a satisfactory performance at low bunch charge [3, 8, 9] it has been replaced with new utca based electronics in summer 2017.

MONITOR TYPES

The successive growth of the FLASH facility from a test to a user facility accounts for the manifold variety of BPM monitors installed in the facility nowadays. The BPMs for which the electronics has been upgraded are summarized in Table 1.

Table 1: Button and Strip-line BPMs

Type	amount	Diameter /mm
button	21	34 or 40 mm
strip-line	33	34 or 44 mm
dump/in-air	6	100 mm
mini-button	13	10 mm
sum	73	

The button type BPMs partially use E-XFEL type feedthroughs [10] and partly older smaller ones. The strip-line monitors [11] promise the best resolution. Other types with upgraded electronics are mentioned for completeness.

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ELECTRONICS SYSTEM OVERVIEW

The upgraded electronics for the 73 BPMs are based on the utca standard. This platform has proven to be a suitable choice concerning reliability, compactness and performance [12].

The RF front-end has been custom designed on a RTM (Rear Transition Module) while the digitizer/FPGA (Field Programmable Gate Array) board is a commercially available AMC (Advanced Mezzanine Carrier) module. The whole BPM system is distributed over ten 19" utca-crates in FLASH. The machine timing is generated in a central module and distributed to all utca-crates in FLASH. Timing receiver modules also located in the crates, are used to generate synchronous triggers, sampling clocks and interrupts for CPU (central processing unit) processes. An overview of the system is shown in Fig. 2.

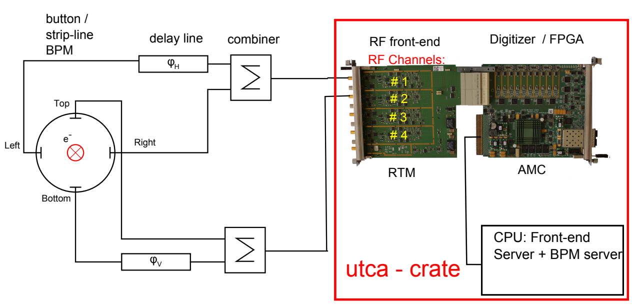

Figure 2: BPM electronics system overview. A second BPM can be connected to the RTM channels 3 and 4. Up to 9 RTM/AMC-pairs are installed in one utca crate.

Analog Electronics

The measurement concept utilizes the DMSP (delayline-multiplex-single-path) method [13–16]. The RF front-end consists of peak detector electronics introduced earlier [13]. The new RF front-end contains the following new features:

- Compact: upgrade to 4 instead of 2 RF channels (2 BPMs can be read out now with one RTM)
- On-board test circuit, enabling on-line RF channel testing
- Optimized sensitivity with anti-parallel schottky diode peak detector circuitry
- Improved signal integrity for differential analog baseband signals and better RF channel separation
- External discharging of peak detector possible

Firmware and Server

The digitization of the buffered peak detector signals takes place on the SIS8300L2D [17] board at a sample rate of 108 MHz with a 16 Bit resolution. The two rectified signals are sampled in two separate ADCs and are digitally combined in the FPGA. The discharging times of the peak detector can easily be adjusted by setting the delay in the firmware. After digitization the beam position and intensity calculation takes place. This is accomplished with the delta over sum algorithm [18] and the multiplication with a simulation based monitor calibration constant. For a given monitor type, beam based measurements indicated an additional calibration factor of +-10, due to variation in the electronics, uncertainty in optics, energy etc. Also the signal losses in the delay-line are compensated in the FPGA. Three automatic gain controls, for the three beamlines in FLASH, set the attenuation states on the RF front-end. The position and intensity data from each BPM front-end server is sent to a device server. Both servers run on the CPU in the crate.

SINGLE SHOT RESOLUTION MEASUREMENTS

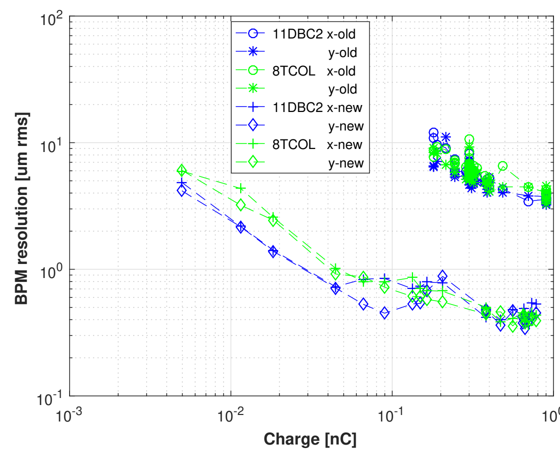

Figure 3: Strip-line BPM resolution (old/new).

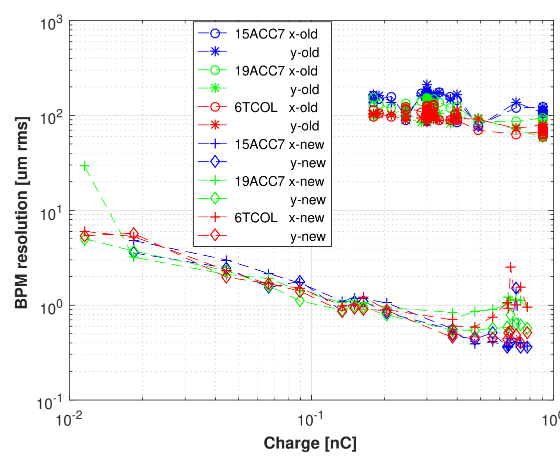

Figure 4: Resolution of button BPMs with E-XFEL Feed-Throughs (old/new).

In order to determine the resolution of one BPM, a linear regression is applied between its reading, in our case from 200 pulses, and the readings from the other BPMs in the machine. Due to the relatively large number of monitors

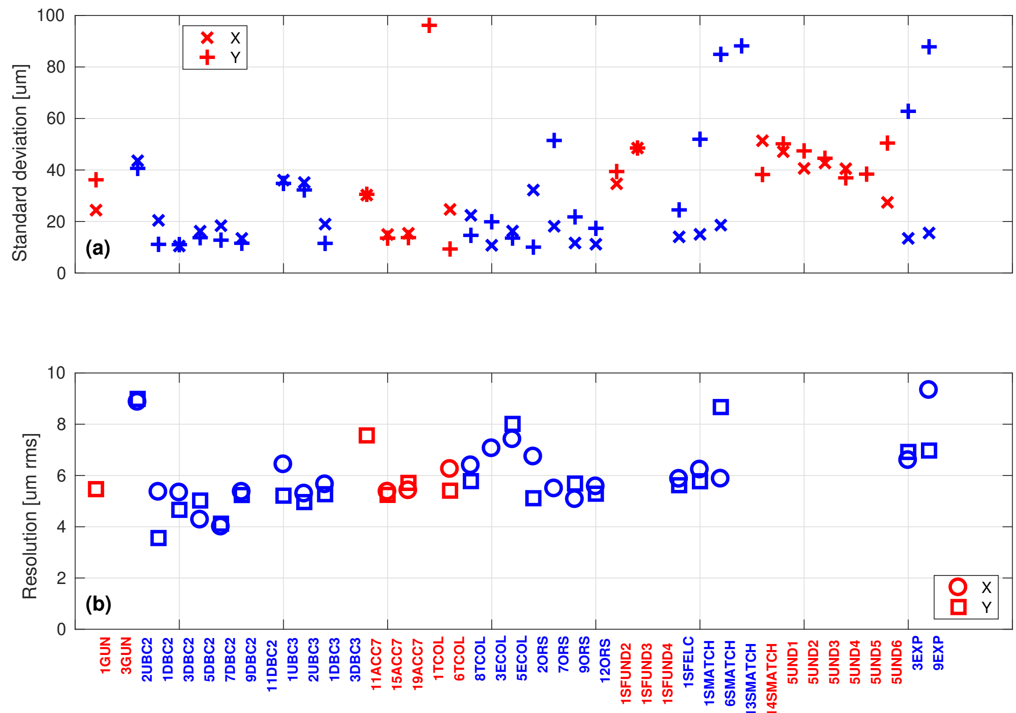

Figure 5: BPM standard deviation (a) and resolution (b) in FLASH 1 at 15 pC. Red: button BPMs, Blue: strip-line BPMs. The standard deviation includes the beam jitter.

and the overall non-periodical lattice along the machine, the contribution of BPMs with larger noise, as well as those which do not correlate well to the evaluated one is reduced, is quasi averaged out. For this the position data from all BPMs in FLASH is read synchronously from a middle layer server. This is done for the old VME, as well as for the new utca based BPM system as a function of the charge. Outstanding results have been achieved with the strip-line and button BPM electronics. Repetitive measurements could confirm the resolution measurements presented here. The results are shown in Fig. 3 and Fig. 4.

A resolution of 10 μm rms was achieved for bunch charges of 15 pC for button BPMs, and even for 10 pC for strip-line monitors. For a charge of 100 pC for both types of BPMs the resolution is of the order of 1 μm rms.

In the study times for ultra short bunches in FLASH it could be shown that the new BPM system can be used to set and optimize the orbit in the machine. A resolution measurement of BPMs distributed along the FLASH1 beam line for a charge of 15 pC is shown in Fig. 5. The upper plot (a) shows the standard deviation of position readings from the BPMs including the correlated beam jitter and the lower plot (b) shows the same but without the beam jitter. For the BPMs in the undulator sections (1SFUND2-4 and 14SMATCH-5UND6), with a beam pipe of ca. 10 mm the resolution is around 30-40 μm, which is still remarkable for their low signal amplitudes.

SUMMARY

All old VME based BPM electronics for button and strip-line monitors have been replaced with a new utca based system. The new low noise amplification of the BPM signals and the broadband receiver architecture in combination with a synchronous digital post-processing enables position readings and therefore machine operation at FLASH at charges down to 15 pC and less. Further studies of individual BPMs are planned for the future.

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