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BEAM POSITION MONITORING OF MULTI-BUNCH ELECTRON BEAMS AT THE FLASH FREE ELECTRON LASER

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Abstract

The superconducting FLASH user facility (Free electron LASer in Hamburg) accelerates 10 electron bunch trains per second, which are mostly used to produce high brilliance XUV and soft X-ray pulses. Each train usually contains up to 600 electron bunches with a typical charge between 100 pC and 1 nC and a minimum bunch spacing of 1 µs. Various types of beam position monitors (BPM) are built in three electron beam lines, having a single bunch resolution of 2 – 100 µm rms. This paper presents multi-bunch position measurements for various types of BPMs and built in at various locations. The dependency of the resolution on the beam offset is also shown.

INTRODUCTION

The Free electron LASer in Hamburg (FLASH) produces ultra-short intense XUV and soft X-ray pulses [1-3]. Beam diagnostic [4] is essential in obtaining and maintaining a high quality electron beam necessary for the self-amplified spontaneous emission effect responsible for producing the photon beams.

Beam Position Monitors (BPMs) are an important part of the beam diagnostics in FLASH. Many types of BPMs are built in along the ca. 250 m of the facility, being distributed in 3 electron beam lines. The BPM type at each location depends on the beam pipe and resolution requirements. Some types can detect bunches with a charge between ca. 10 to 1000 pC, and have a single bunch resolution of 2 to 15 µm rms. Others need a higher charge, and have higher values for the resolution, but they are in most cases still in accordance with the local demands.

While the behavior of the BPMs is in general well understood, only the behavior of the first bunch has been so far studied in detail. In this paper we present the analysis of each bunch in long trains. The single bunch behavior for different bunch offsets is also shown.

The FLASH Facility

An overview of the FLASH layout is shown in Fig. 1 [3]. A photoelectric gun produces every 100 ms electron bunch trains with a length of up to 600 µs and a repetition frequency of up to 1 MHz. TESLA superconducting structures accelerate them to an energy of up to 1.25 GeV. Two bunch compressors are used to reduce the bunch length to tens till hundreds of fs. The train is then split to the two undulator beamlines, FLASH1 and FLASH2, where photon pulses are produced. A third beam line splits off of FLASH2 and accommodates a laser-plasma experiment, FLASHForward [5]. Table 1 gives a summary of the main parameters of the electron and photon beams.

Note that currently the facility is at the end of an upgrade and refurbishment shutdown, with the main goals of increasing the energy, installing a laser heater, and a new bunch compressor [6].

Beam Position Monitors in FLASH

The different kinds of BPMs installed in the accelerator are able to measure the transverse position of each bunch within a train. Each type has several designs, depending on the beam pipe, whose diameter ranges from 10 to ca. 100 mm. There are button BPMs (one of the designs is described here [7]) and stripline BPMs [8], both types with electronics developed for FLASH [9]. Also there are cavity BPMs with electronics developed for the European XFEL [10] in the undulator section in FLASH2, as well as “cold” cavity BPMs in the accelerating modules [11].

The single bunch resolution has been evaluated for various charges and beam offsets. The method used for calculation is based on linear regression and is described in [12].

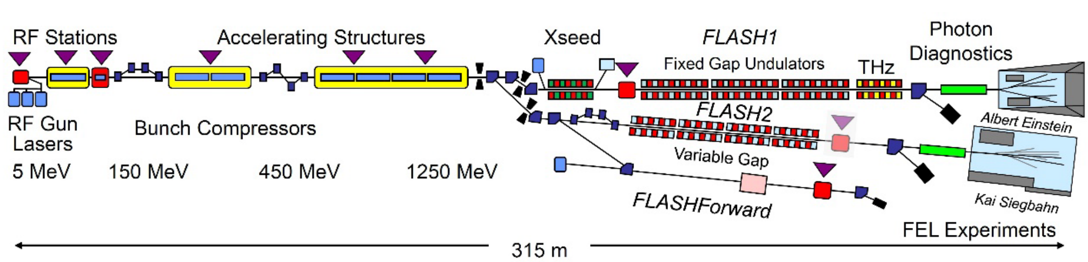

Figure 1: Schematic layout of FLASH [3].

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Table 1: Operational Parameters of the Electron and Photon Beams [2]

Parameter	FLASH1	FLASH2	Units
Electron beam:			
Beam energy	0.38-1.25	0.38-1.25	GeV
Normalised emittance (rms)	0.5-1	0.5-1	mm mrad
Bunch charge	0.1-1.2	0.02-1	nC
Bunches per second	1-5000	1-5000	
Photon beam:			
Wavelength	51-4.2	90-4	nm
Pulse duration (FWHM)	<30-200	<30-200	fs
Pulse energy	1-500	1-1000	µJ

Figure 2 shows typical resolutions measured for a FLASH1 bunch of charge of 0.4 nC (upper plot) and 0.3 nC for the FLASH2 case. The bunches for both beamlines pass a common beamline until ca. 150 m before being directed towards one of the 2 beamlines. Note that most BPMs have a single bunch resolution well below 10 µm rms, the requirement for these charges being 30 µm for most of them, and 10 µm for the undulator section (ca. 200 – 230 m in FLASH1 and ca. 190 – 230 m in FLASH2).

Most button BPMs (red plus and diamond symbols) have a 34 or 40.5 mm beam pipe diameter (monitor constant of 9, respectively 10.6 mm) and typically have a resolution better than 5 µm. In the FLASH1 beamline there are button BPMs with 10 mm beam pipe diameter and pencil-like antennas (constant 2.5 mm). These achieve similar resolution with additional amplifiers. Large button BPMs have a diameter of ca. 100 mm (monitor constant of 25 mm), as it is the case in the plot for a monitor at ca. 140 m in the common beam line. These show a lower resolution, above 5 µm. Most stripline BPMs have a beam pipe of 34 mm, and a constant around 9 mm, showing a typical resolution below 4 µm rms.

The cold cavity BPMs installed in the accelerating modules in the common part were designed for larger bunch charges, in general having a less reliable performance at charges below 0.4 nC. For higher charges their resolution is usually below 30 µm therefore also satisfying the requirements.

A summary of the typical single bunch resolution, measurement range for the charge and transverse offset is given in Table 2. The dependency of the resolution on the beam charge and offset is given later in this paper.

Table 2: Typical BPM Parameters

BPM-type	Charge [nC]	Offset [% diam.]	Single-bunch resolution [µm rms]
Button	0.02-1	ca. 30%	3-100
Stripline	0.01-1	ca. 30%	2-15
Cavity	0.01-1	ca. 10%	1-3
Cold cavity	0.4-1.5	ca. 20%	20-100

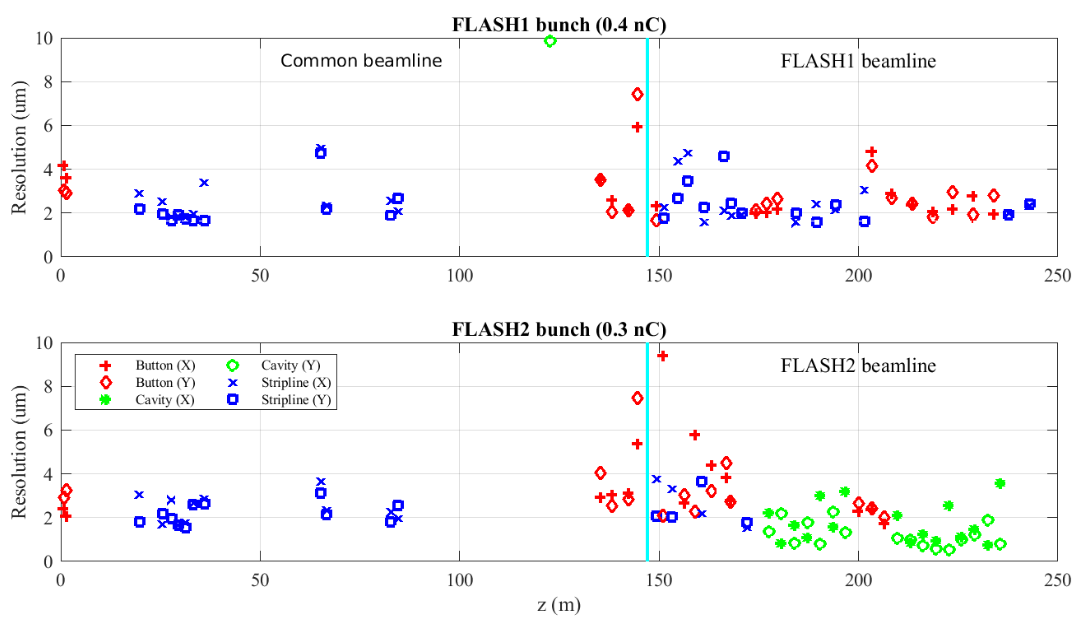

Figure 2: Resolution of the first bunch in the FLASH1 train (upper plot, 0.4 nC) and the FLASH2 one (lower plot, 0.3 nC).

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POSITION RESOLUTION ALONG THE BUNCH TRAIN

In order to check if the performance of the beam position monitoring described in the previous section is maintained along the bunch train, we analysed each bunch in long trains for FLASH1. The method mentioned above for determining the resolution is now used for each bunch. Note that in FLASH1 no cavity BPMs are installed, except in the cryo-modules [11]. Since these are at or below the lower limit of their charge range, are not shown here. Therefore, we give results for button and stripline BPMs. The MTCA-based reading of these two types of BPMs is described in [9].

Data from 200 bunch trains were collected, each with 340 bunches of 0.2 – 0.4 nC charge. The beam energy was ca. 1 GeV. The bunch repetition frequency was varied between 1000 and 50 kHz. Typical results for one button and one stripline BPM are shown in Figs. 3 and 4 respectively. Both BPMs are located after the accelerating section at the beginning of the FLASH1 beamline, at around 150 m.

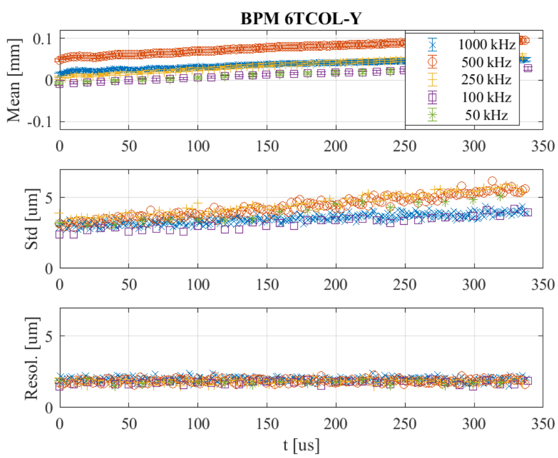

Figure 3: Mean (up), standard deviation (middle) and resolution (down) of the vertical bunch position for each bunch along the pulse train for various bunch repetition frequencies for a button BPM with an inner beam pipe diameter of 34 mm.

In each figure, the upper plot displays the average beam position reading of the 200 pulses and the middle one the standard deviation for each bunch. The lower plot gives the single bunch resolution. The various curves correspond to bunch trains with different bunch frequencies.

One notices in the upper plots in both figures that the offset of a given bunch is different for different frequencies. Already the orbit of the first bunch in the train is different. It turns out that also the charge is different for different bunch frequencies, as seen in the upper plot in Fig. 5. This figure shows the analysis of the charge reading for one toroid in the facility, for each bunch in the train, similar to the analysis made for BPMs. The charge is slightly different for the first few µs, and varies between 0.2 nC for a bunch frequency of 1 MHz to 0.4 nC for 50 kHz.

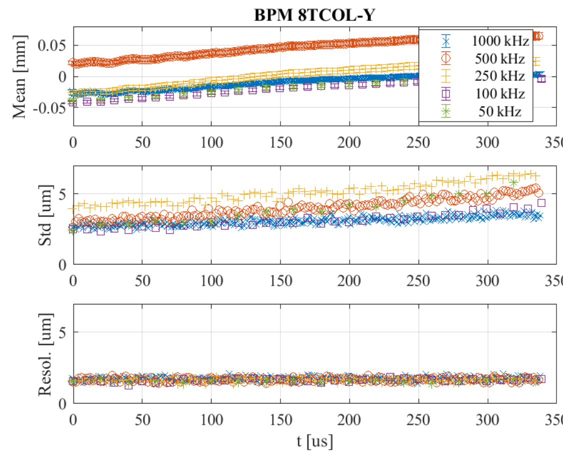

Figure 4: Similar to Fig. 3 for a stripline BPM with an inner beam pipe diameter of 34 mm.

This change in the charge may explain at least in part the difference in the standard deviation for the position as well as the charge reading for a given bunch (middle plots in Figs. 3–5). The difference in the beam position for various bunch frequencies plays a minor role, as it will be seen in the next section.

It is interesting to note in Figs. 3 and 4 that the bunch offset varies along the bunch train. This is already seen for the first BPM after the gun. Moreover, also the standard deviation of the reading changes along the train. The resolution however remains constant for both BPMs.

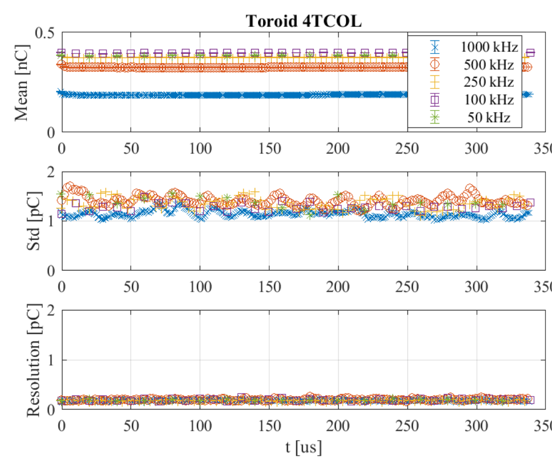

Figure 5: Mean (up), standard deviation (middle) and resolution (down) of the charge reading from one toroid for each bunch along the pulse train for various bunch repetition frequencies.

The question arose, whether there is a pattern in the BPM reading along the train. Figure 6 shows the Fourier transform of each of the plots in Fig. 4 for the stripline BPM. No clear pattern can be recognized for any of the plots.

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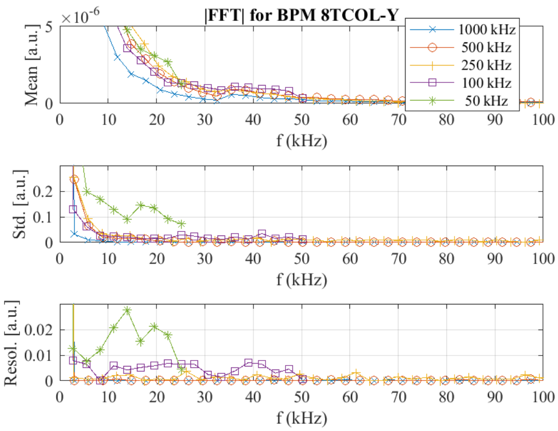

Figure 6: FFT of each plot in Fig. 4.

BPM RESOLUTION VERSUS BUNCH OFFSET

In order to find the dependency of the BPM resolution with the beam offset, single bunch pulses with various offsets at three subsequent stripline BPMs were generated (left plot in Fig. 7). The bunch charge was ca. 0.4 nC. In each case 200 pulses were measured from which the resolution was calculated. The results are shown in the right plot of the same figure.

One observes that the resolution stays below 4 µm rms for a wide range of beam offsets of more than ±4 mm, the beam pipe diameter being 34 mm. For larger offsets the resolution degrades considerably.

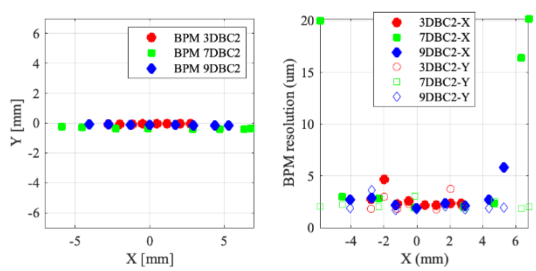

Figure 7: Dependency of the single bunch BPM resolution on the beam position (right) and the corresponding beam position readings (left).

Note that the dependency of the BPM resolution on the beam charge can be found in [9].

SUMMARY

In this paper the dependency of the single bunch resolution for button and stripline BPMs in the FLASH facility at DESY, Hamburg, along bunch trains was studied. Various bunch frequencies were generated during this study. While there is a variation of the beam position as well as of the standard deviation of the position reading along the bunch train, no dependence of the resolution was observed.

Further measurements show that the single bunch resolution stays unchanged within a transverse range of the stripline-BPMs larger that ±4 mm.

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