DEVELOPMENT STATUS AND PERFORMANCE STUDIES OF THE NEW MICROTCA BASED BUTTON AND STRIP-LINE BPM ELECTRONICS AT FLASH 2

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Abstract

The FLASH (Free Electron Laser in Hamburg) facility at DESY (Deutsches Elektronen-Synchrotron) in Germany has been extended by the new undulator line FLASH 2 providing twice as many experimental stations for users in the future [1] . After the acceleration of the electron bunch train up to 1.2 GeV in FLASH, a part of the beam can be kicked into FLASH 2, while the other is going to the old undulator line of FLASH 1. The commissioning phase started in early 2014 and continues parasitically during user operation in FLASH 1. One key point during first beam commissioning is the availability of standard diagnostic devices such as Beam Position Monitors (BPMs) [2]. In the last couple of years new electronics for button and strip-line BPMs have been developed, based on the MTCA.4 standard [3–6]. This new Low Charge BPM (LCBPM) system is designed to work with bunch charges as small as 100 pC in contrast to the old systems at FLASH initially designed for bunch charges of 1 nC and higher. This paper summarizes the development status of the new BPM system and discusses the results of resolution studies of the BPM system.

INTRODUCTION

The demand for beam time at the user facility FLASH increased substantially in the past. In order to fulfill this need the facility has been extended by a new undulator beam line for SASE generation called FLASH2. The desired charges for FLASH 1 and FLASH 2 can be adjusted separately from two laser systems. FLASH2 has seen the first beam on 4th March 2014 and was able to provide SASE (Self Amplified Spontaneous Emission) for the first time on 20 August 2014 [7, 8]. This was done simultaneously to SASE delivery in FLASH1. The electron beam delivered to FLASH2 is accelerated together with the beam for FLASH 1 within the same RF (Radio Frequency) pulse to up to 1.2 GeV after approximately 150 m from the gun and is then kicked....Part of the diagnostics in FLASH2 are button and strip-line monitors at 16 locations in the machine utilizing new MTCA.4 electronics designed at DESY [3–6]. Challenges in the development of this system are the single-bunch resolution requirement of 50 µm, operation at charges below 100 pC and a high bunch repetition rate of up to 4.5 MHz. These requirements were chosen to be compatible with the requirements for the European XFEL [9]. The development status and resolution studies of the BPM system are summarized in this paper.

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MACHINE AND SYSTEM OVERVIEW

The new FLASH2 undulator beam line runs in parallel to the old FLASH1 undulator beam line as it can be seen in Figure 1. It is divided into several sections namely EXTRACTION, SEED, SASE, BURN, and DUMP. Button and strip-line monitors are installed in different locations.

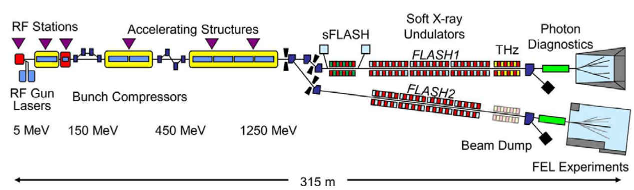

Figure 1: Section overview FLASH.

Most of the LCBPMs are distributed along the EXTRACTION section at the beginning of FLASH2 with nine BPMs. Four BPMs are in the BURN/DUMP section. Due to space limitations in the SASE section three button BPMs have been installed here as well instead of using the more preferable cavity BPMs which offer the required resolution for orbit tuning in the SASE section [10, 11]. A variety of different beam pipe diameters for the button BPMs and a few refurbished strip-line BPMs, with different RF cable lengths ranging from 35 to 58 m, required the development of a very robust but also flexible BPM electronics. Table 1 summarizes all types of BPMs for which the electronics are currently in operation. Electromagnetic field simulations [12] delivered the monitor constants. The button type concept is similar as for the European-XFEL that has been reported in [13], while the strip-line monitors are an old design described in [14].

Table 1: Types of Beam Position Monitors Installed in FLASH2 and Corresponding Monitor Constants

Type	amount	Beam Pipe	Monitor constant
button	2	40 mm	10.6 mm
button	4	34 mm	9.06 mm
button	3	100 mm	23.84 mm
strip-line	4	44 mm	8.678 mm
in-air	1	100 mm	31.25 mm
button	3	10 mm	2.55 mm

An overview of a BPM system can be seen in Figure 2.

The beam excited RF signals in the horizontal and vertical plane respectively are combined after a delay of 100 ns to suppress interference with the next bunch in the train. This so-called Delay Multiplex Single Path Technology (DM-

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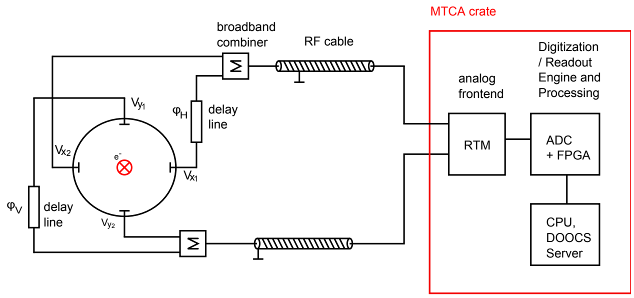

Figure 2: Beam Position Monitor System Overview.

SPT) [15, 16] method has been successfully in operation for many years in HERA[1] at DESY. It successfully proved to suppress the common mode EMI disturbances on the RF cable from the tunnel to the electronic racks. It also halves the number of necessary ADC (Analog Digital Converter) channels for each BPM. The electronics for signal conditioning and processing are separated into an analog RTM (Rear Transition Module) and a digital card. The two cards are housed in a MTCA.4 crate. The position calculation takes place in the Firmware on the digital card and is given by the normalized difference of the signal on opposite electrodes [17]. This position information can then be read from a device server which sends the position information to a so called middle layer server. This collects the data to be displayed in an orbit panel for operation and sends the data to a digital Data Aquisition System (DAQ).

ELECTRONICS

Analog Signal Conditioning

A typical input and output signal for one channel of the radio frequency receiver from a button BPM is shown in Figure 3. The raw data for a single bunch in one plane of the BPM is shown. The data has been taken on a test output port on the analog front-end with a 2 GHz oscilloscope. In order to meet the requirement to measure bunch trains with a repetition rate of up to 4.5 MHz, a delay of 100 ns between opposite electrodes and a peak detector with discharger topology has been chosen. With this method the bunches in the train can be well separated. Moreover the receiver has a large dynamic range to adapt to the specified charge range from 1nC down to 20pC and the measurement at large beam offsets. More details of the analog front-end can be found in [6].

Digital Raw Signal

The position calculation takes place in an FPGA (Field Programmable Gate Array) on a digitizer card. The sample rate of the signal is 125 MHz and the resolution is16 Bits. A typical digitized raw signal for one plane of a single bunch is shown in Figure 4. Due to the additional buffer amplifier and anti aliasing filtering the signal shape looks different from what is measured on the analog test port.

[1] Hadron Elektron Ring Anlage

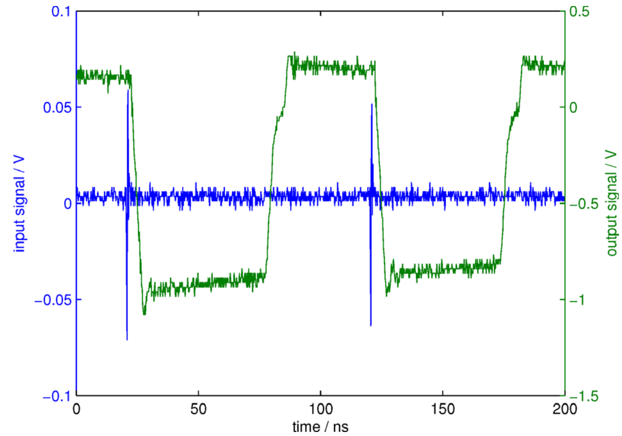

Figure 3: Blue: A typical input signal for the BPM electronics. Green: A typical output signal from the analog front-end before digitization.

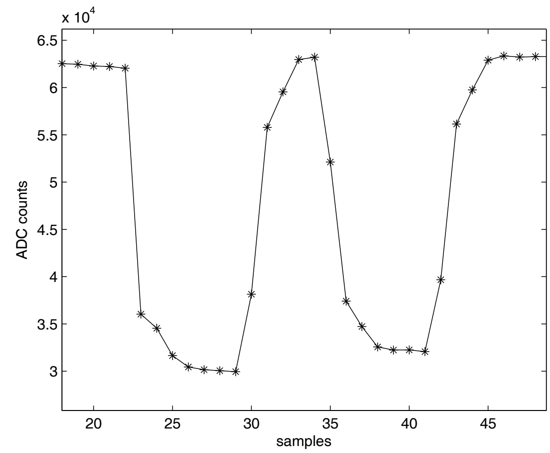

Figure 4: Typical digital raw data.

The custom made firmware (FW) is operating in real time and delivers bunch by bunch information at its output registers. The FW contains registers to adjust the step attenuators on the analog RF front-end. Currently the FW is operating in the so-called quasi-autarchic mode. In this mode the FW receives an external pre-trigger from the accelerator timing system. All other bunch related information is derived from this initial trigger inside the FW. The measured resolution of this mode is discussed in the later section. The best resolution is expected for the fully timing coupled mode in which the sampling points are more stable in the aquired signal.

SYSTEM STATUS

The beam positions calculation has been processed in the FW and are then collected by a device server after the bunch train and are then sent to a BPM middle layer server which displays the beam position for steering purposes to the operator. The middle layer server also provides a time stamp to the event based measurements which is necessary for later data analysis. The insufficient signal strength for three button monitors in the SASE section has been overcome

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by the installation of custom made pre-amplifiers inside the tunnel. The position reading is also possible at these locations now.

RESOLUTION MEASUREMENTS

One key feature in the characterization of the BPM is its electronics resolution. In [6] it has been shown that this BPM system already fulfils the single shot resolution of 50 µm. Nevertheless these measurements were not free of beam jitter . In order to characterize the true electronics resolution the beam based fluctuations and the electronics noise contribution to the position measurement from each BPM have to be sparated . One method to separate the two sources relies on the fact that the transverse beam movement for the single bunch position measured by all BPMs in the machine is a correlated contribution to the measurement while the individual noise of each BPM remains uncorrelated. Under such conditions a prediction method based on linear regression can be applied. One pre condition to identify correlated and uncorrelated contributions to the BPM readings is the synchronous reading of beam positions from all BPMs. The implementation of the middle layer allows this. After taking data of 300 subsequent bunches at a charge of 85 pC and applying the method which has been described in detail in [18] a position prediction vector could be identified.

It is based on all 16 button and strip-line BPM readings in FLASH 2 excluding the BPM under test. An example for one button and one strip-line BPM under test plotted against their prediction vectors are shown in Figures 5 and 6.

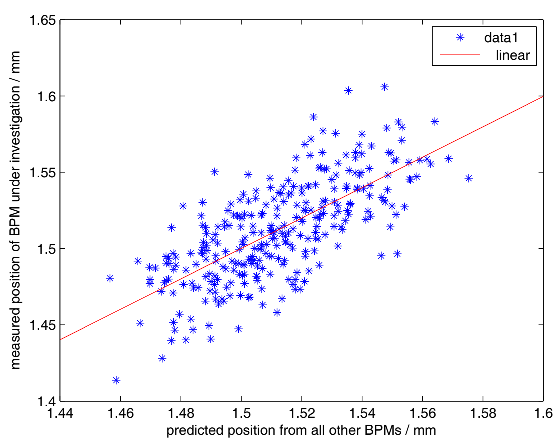

Figure 5: Strip-line monitor correlation plot.

The standard deviation for the strip-line and button monitors are 33 µm and 54 µm respectively. These values include correlated and uncorrelated contributions to the measurement. The residual standard deviation of electronics under test is 23 µm for the strip-line monitor and 32 µm for the button BPM. These values represent the uncorrelated contribution to the measurement and identify the electronics resolution.

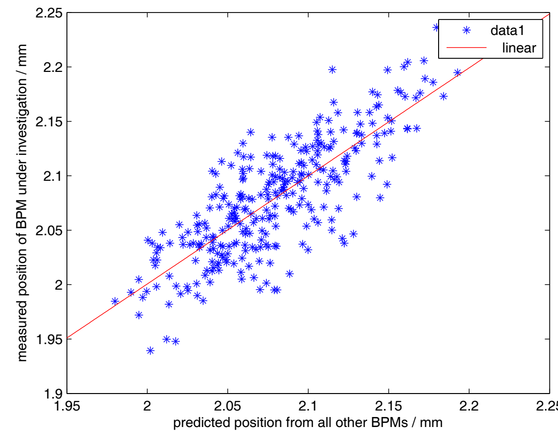

Figure 6: Button monitor Correlation plot

SUMMARY AND OUTLOOK

A new MicroTCA based BPM system has been summarized in this paper. Its performance has been studied using linear regression and it has been found to fulfil the resolution specifications. An improved resolution is expected when a fully timing-coupled FW mode is calculating the BPM position. The development of this mode is under way. In addition a FW upgrade of the Register Interface to a DMA(Direct Memory Access) driver for advanced data throughput is currently investigated.

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