FLASH Undulator BPM Commissioning and Beam Characterization Results.

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Abstract

- Commissioning of FLASH2 has started, a new soft X-ray FEL undulator line at the DESY FLASH facility.
- 17 cavity beam position monitor (CBPM) pick-ups and electronics [1] developed for the European XFEL (E-XFEL) included.
- Four CBPMs are available at FLASH1 for test and development.
- The CBPM system enables an unprecedented position and charge resolution at FLASH.
- Results of first beam measurements as well as correlations with other FLASH diagnostics systems are reported.

Introduction

- Cavity BPMs with sub-micron noise and drift will be used for the alignment of the electron beam with the photon beam in the undulator area at the European X-FEL [2]; for a detailed description of a cavity BPM see [3,4].
- Two types of CBPMs: 10 mm aperture and 100 mm length, a second CBPM type with 40.5 mm aperture and 255 mm length will be installed in some locations.
- A test area for the verification of the performance of both CBPM types has been installed at FLASH1 after the last undulator.
- The CBPM electronics, including its embedded FPGA firmware and software, is provided in an In-kind contribution from PSI.
- Both CBPM have the same electronics because the BPM pickups have the same frequency of 3.3 GHz and similar loaded Q for their position and reference resonator.
- In addition to FLASH1, a second undulator beamline FLASH2 [5] has been built to extend the capability of the FLASH soft X-ray FEL facility [6] with 17 CBPMs.

CBPMs at FLASH1

Figure 1: CBPM test-stand at FLASH1

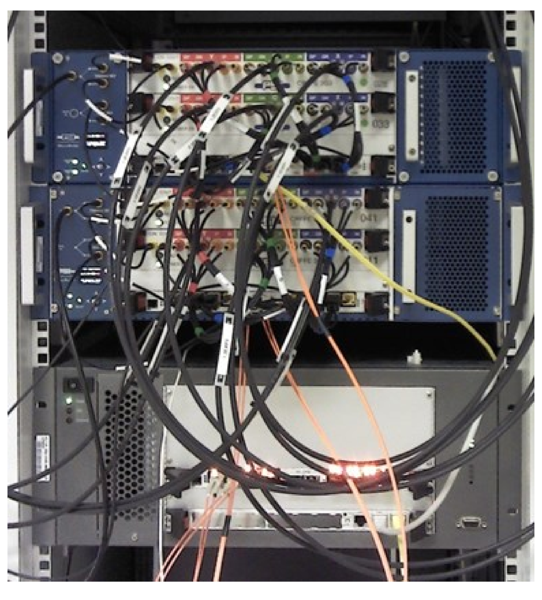

Figure 2: CBPM Electronics provided by PSI for FLASH1 and FLASH2.

Beam based calibration

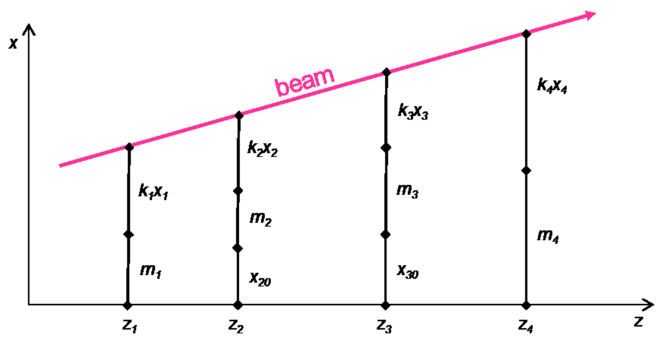

Figure 3: Sketch for the calculation of the calibration.

$$\frac{(k_2x_2+m_2+x_{20})-(k_1x_1+m_1)}{z_2-z_1=z_{12}}=\frac{(k_4x_4+m_4)-(k_3x_3+m_3+x_{30})}{z_4-z_3=z_{34}}$$

$$\frac{m_2-m_1}{z_{12}}+\frac{m_3-m_4}{z_{34}}=\frac{k_1x_1-k_2x_2-x_{20}}{z_{12}}+\frac{k_4x_4-k_3x_3-x_{30}}{z_{34}}$$

$$=\begin{pmatrix}\frac{x_1}{z_{12}} & -\frac{x_2}{z_{12}} & -\frac{x_3}{z_{34}} & \frac{x_4}{z_{34}} & -\frac{1}{z_{12}} & -\frac{1}{z_{34}}\end{pmatrix}\begin{pmatrix}k_1\\k_2\\k_3\\k_4\\x_{20}\\x_{30}\end{pmatrix}$$

Written in vectors for the *j* measurement: $m_j=\overrightarrow{P_j}\,\vec{k}$

For several measurements: $\vec{M}=P\,\vec{k}$

with *P* a matrix. The solution is: $\vec{k}=P^{-1}\vec{M}$

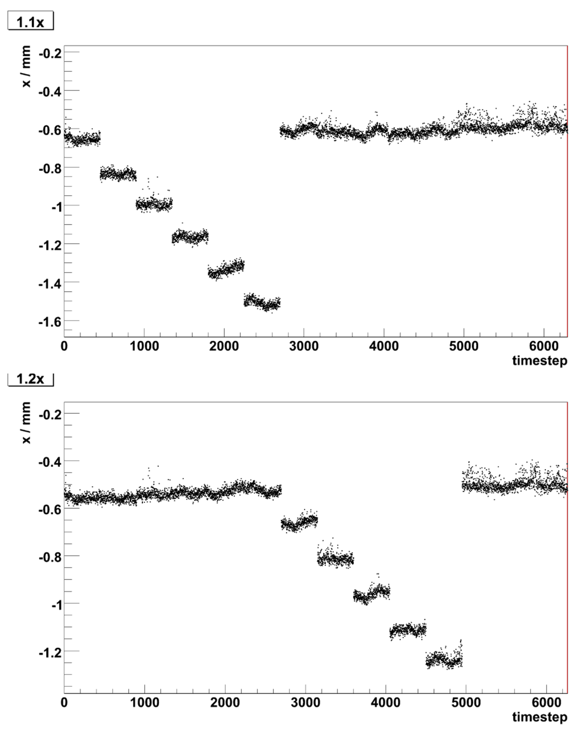

Figure 4: Position readings for different mover positions in x for first (1.1x) and second (1.2x) CBPM.

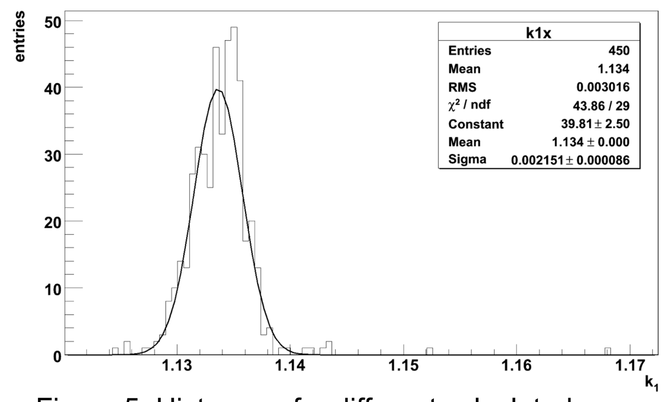

Figure 5: Histogram for different calculated correction values of first CBPM in horizontal direction with Gaussian fit.

This method was applied to the four CBPMs. Each CBPM was moved separately with about 200µm step size, see Fig.4. For each CBPM, 5 steps were used, with 450 position and charge measurements for each step. The histogram in Fig. 5 shows an example from the resulting calibration that we obtained from the measurement.

Resolution measurements

- With the calibrated CBPM of the test-stand one can measure the beam positions and compare them with each other.
- The 3 BPM method is applied which is described in detail in [3]. Here two BPMs are used to predict the position at the third BPM. The difference from measured and predicted value results in a residual; one example of a residual histogram is shown in Fig 6.
- The Gaussian fit delivers a standard deviation which is used with a geometric factor (see [3]) to calculate the CBPM noise.
- The noise for both transverse planes are shown in Fig. 7 for different beam offsets at a charge of about 240 pC.

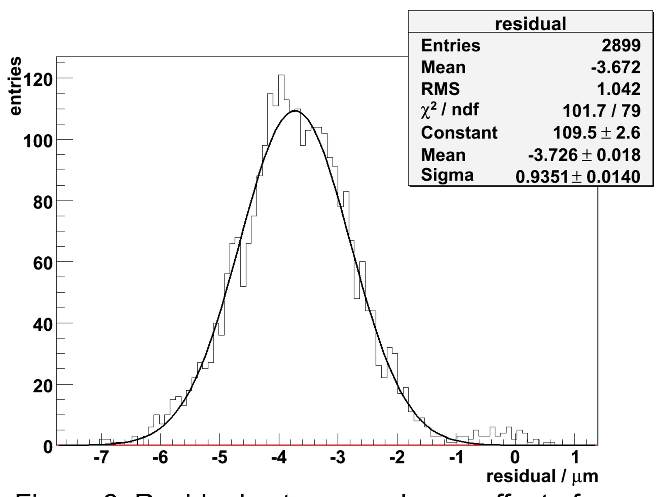

Figure 6: Residuals at a mean beam offset of 0.46 mm and charge 240 pC with Gaussian fit.

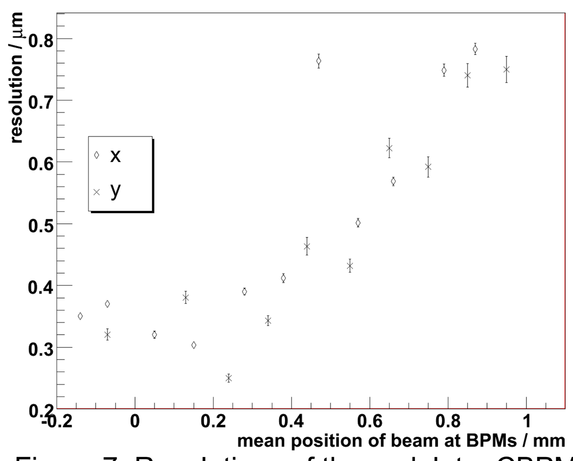

Figure 7: Resolutions of the undulator CBPMs at FLASH1 for different mean beam offsets in *x* and *y* for a charge of about 240 pC.

- The noise is increasing with the beam offset as expected, since the normalization of the position cavity to the reference cavity signal causes noise of the position that increases with larger beam offsets.
- For E-XFEL, the required single-bunch position noise for a stable beam with constant charge is below 1 µm for ±0.5 mm measurement range and 0.1 – 1 nC bunch charge.
- This requirement is already fulfilled by the E-XFEL pre-series electronics used in FLASH1 and FLASH2, where further improvements for the final system are expected by improved calibration and signal processing techniques.
- In addition one can compare the measured charge values of each CBPM and correlate them to calculate the charge resolution; for 240 pC charge, a resolution of 0.13 pC was obtained.

CBPMs at FLASH2

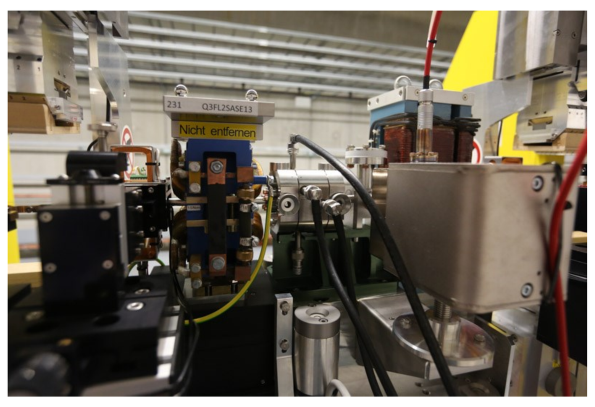

Figure 8: Undulator CBPM in an intersection of FLASH2.

Figure 9: Undulator electronics for FLASH2 provided by PSI at the bottom part with 4 front-ends. Above is a µTCA crate with an FPGA/SFP board for the communication between PSI electronics and FLASH control system via fiber optic multi-gigabit links.

Charge measurements

- In FLASH2 17 CBPMs are installed. Before first beam, the CBPMs have already been pre-calibrated, using e.g. measured RF properties of the pickups and cables and signal generators for the electronics. Therefore only the suitable trigger delay needed to be adjusted.
- For the absolute calibration of the CBPM charge measurement, the standard FLASH Toroid charge monitor was used. Thanks to a good pre-calibration, only a correction of 2.9% was necessary.
- A mean charge value for each bunch is calculated such that the deviation due to a single monitor noise is negligible, except one monitor under test. This results in a difference between expected and measured charge for the monitor under test, see an example in Fig. 10.
- The standard deviation from the Gaussian fit shows the sum from systematical and statistical measurement errors, defined here as sum error. For all charge monitors these are shown in Fig. 11.

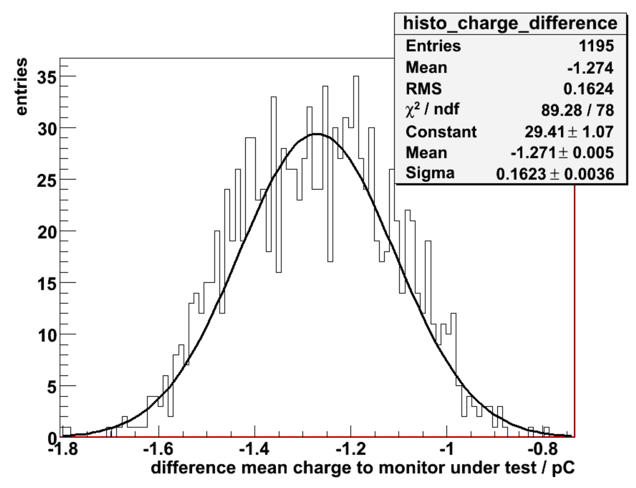

Figure 10: Difference between mean charge value to the monitor under test: here CBPM with the monitor number 19 with Gaussian fit; charge of about 100 pC.

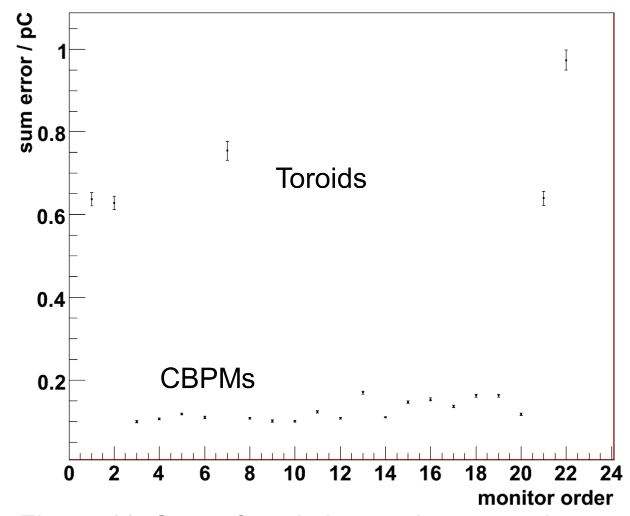

Figure 11: Sum of statistical and systematic errors of charge monitor correlation at FLASH2 at a charge of about 100 pC, with active automatic gain control of the CBPMs, ordered according beam direction.

Position measurements

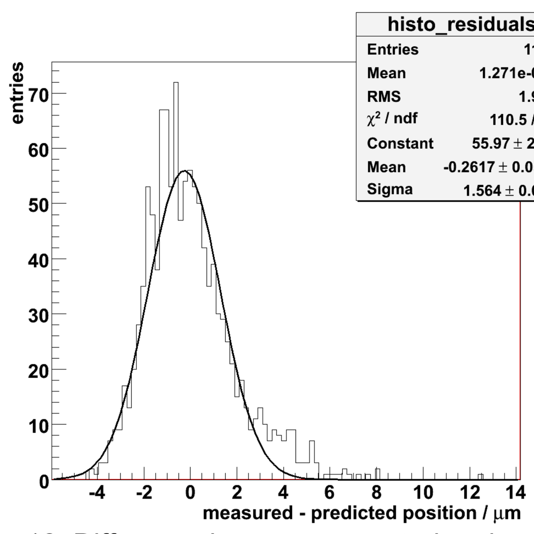

Figure 12: Difference between expected and measured position with Gaussian fit of a CBPM with monitor number 4 for position error calculation at the horizontal plane.

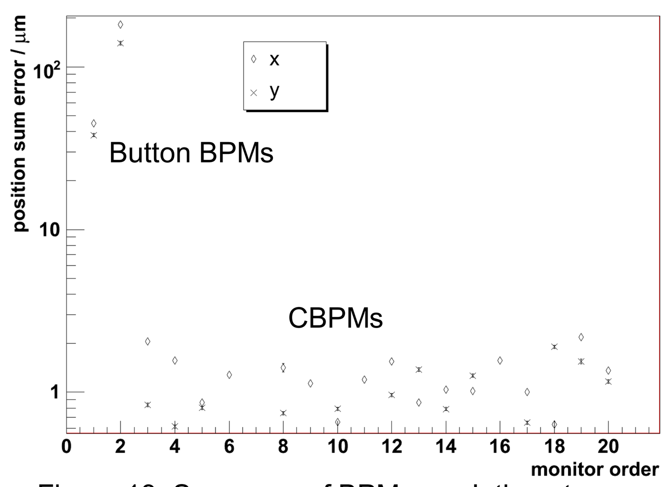

Figure 13: Sum error of BPM correlation at FLASH2 in both transverse planes for a charge of about 100 pC.

- To obtain the position sum error (including statistical and systematical errors) two button BPMs after the acceleration modules and all CBPMs at FLASH2 are used, the method is described in [7], results are shown in Figs. 12 and 13.
- Due to different beam positions, e.g. vertical sum error vs. mean beam position (see Fig. 14), the sum error is different at each CBPM, similar to the results shown in Fig. 7.
- Sum error is much better for the CBPMs compared to the button BPMs.
- The sum error obtained for the CBPMs has several contributions: frequent changes of the attenuators, the ADCs of the BPMs may saturate with large amplitudes, indicated via a valid flag but not yet recorded by the control system, mechanical vibrations, and others.
- A more detailed analysis of the individual contributions is in progress, where the goal is to minimize systematic contributions to the BPM measurement error, see [8].

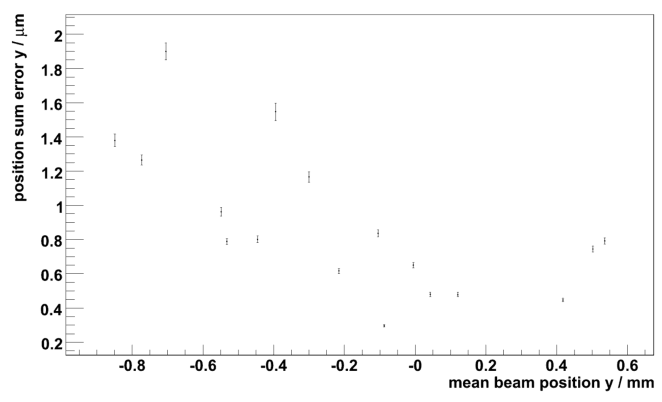

Figure 14: Sum error of CBPM correlation measurement at FLASH2 at the vertical plane with a charge of about 100 pC as a function of mean beam position.

Summary

The development of the CBPM system for the European XFEL is in an advanced state. An E-XFEL pre-series version of the CBPM pickups and electronics has been installed and tested in FLASH1 and FLASH2, and already fulfills the requirements for E-XFEL. Future activities will focus on improvement of lab and beam-based calibration techniques, as well as on improved automated range control and digital signal processing to further improve the CBPM system performance.

References

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