

DEVELOPMENT OF CAVITY BPM FOR THE EUROPEAN XFEL

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Abstract

The European XFEL, currently under construction at the DESY site in Hamburg, requires high precision orbit control in the long undulator sections and in some other locations of the machine, like bunch compressors, matching sections, or for the intra bunch train feedback system. Due to the pulsed operation of the facility the high precision has to be reached by single bunch measurements. For highest precision cavity BPMs will be used at the European XFEL. This paper reports on the measurement on two types of cavity BPMs, for the intersection of the undulators with 10 mm beam pipe and for sections with a standard beam pipe diameter of 40.5 mm. The prototypes for both types show the properties as expected from simulation results. Furthermore, the industrialization process with some traps and their cures of the production process will be discussed.

INTRODUCTION

XFELs require high precision orbit control in their long undulator and in special matching sections e. g. intra bunch feedback system. So far only cavity BPMs achieve the required performance and will be used at the European XFEL, one between each of the up to 116 undulators [1] and few upstream.

The cavity BPM consists of a coaxial dipole resonator with four symmetric arranged slots and a reference resonator. A charged particle beam excites electromagnetic fields. Antennas in the slots and the reference resonator observe the beam induced voltage. The signal coupled out from the dipole resonator is the TM_{11} mode (the dipole mode is spatial filtered by the arrangement of the coupling slots), which is proportional to the beam offset and charge. Charge and phase normalization are done with the signal from the reference resonator (TM_{01} mode which is proportional to the charge only). Thus the beam position is observed. The phase relation between dipole and reference resonator determines the sign of the displacement.

Two kind of cavity BPMs are developed for the European XFEL based on the design from [2]: one with 10 mm beam pipe inner diameter for the undulator area and one with 40.5 mm being the standard beam pipe diameter for the warm beamlines. The difference results in a longer beamline BPM because the strong reference signal with the same resonance frequency of 3.3 GHz would couple to the dipole resonator through the pipe. A certain distance, here 19 cm is used to avoid this effect, resulting in an overall length of 25 cm for the beamline cavity BPM. The undulator cavity BPM is 10 cm long, see Fig. 1. Both BPMs are

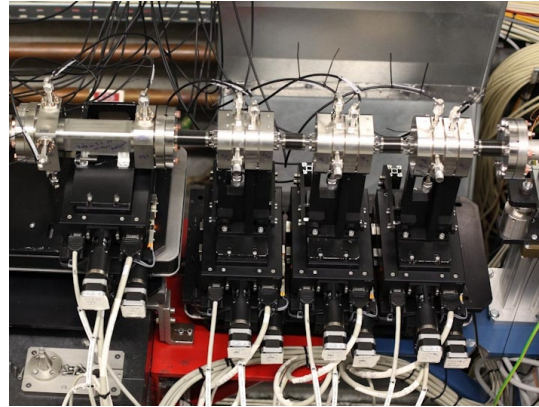


Figure 1: Photo of the BPM test stand at FLASH. The beam enters from the right hand side and traverses 3 undulator cavity BPM and 1 beamline BPM.

made from stainless steel discs brazed together to form the resonators.

This paper reports on the beam measurement at FLASH, done in Summer 2010. The data was taken with an oscilloscope Tektronix 6604, because the electronics for the BPMs are not ready for beam test at that time. The oscilloscope has 4 input channels, therefore 3 BPMs in one plane plus a reference resonator can be used to measure the position of the same electron beam at 3 places. In addition difficulties of the pre-series production are discussed.

MEASUREMENTS

Three undulator (shortcuts 1.1, 1.2 and 1.3) and one beamline BPM (shortcut 2.1) was installed beginning of 2010 at FLASH on translation stages each, see Fig. 1. This gives the possibility to measure the individual sensitivity and resolution. In the following the measurements and results are described.

Reference Resonator

At first one has to calibrate the amplitude of the 3.3 GHz signal with the charge. The voltage as a function of time is shown in Fig. 2. In the following the attenuation of signal amplitude between BPM and oscilloscope are corrected. The amplitude is determined by a fit on the measurement and compared with charge measurement from a Toroid, see Fig. 3. The error bars are standard deviations of several measurements. The mean value of the sensitivity for the undulator BPMs is $(60.0 \pm 0.3_{\text{stat.}})$ V/nC, expected 43.5 V/nC. The sensitivity of the beamline BPM is $(66.9 \pm 0.5_{\text{stat.}})$ V/nC, expected 42.9 V/nC. The difference

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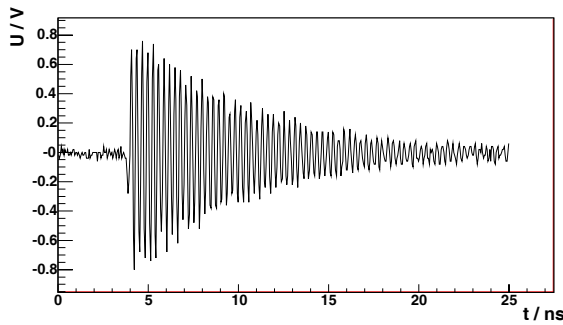


Figure 2: Voltage as a function of time of the beamline reference resonator.

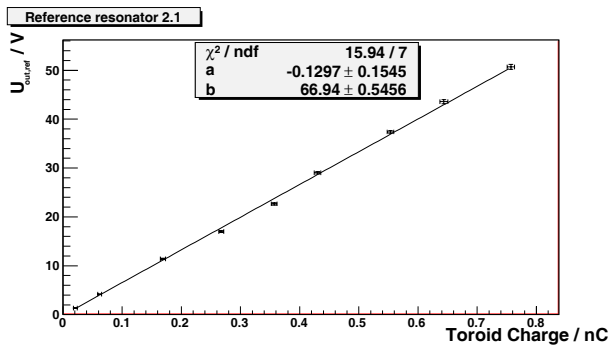


Figure 3: Amplitude of the beamline reference resonator as a function of the next Toroid with fit. The slope b corresponds to the sensitivity.

between measurement and expectation is caused by a problem of the used simulation. The reference resonator has one antenna, breaking the symmetry of the cavity. Therefore the field distribution is shifted from the center of the BPM to the antenna. This complicates the simulation. Tests with symmetric reference resonators having two antennas give much better agreement between measurement and expectation, where the symmetry is given.

Dipole Resonator

The sensitivity of the dipole amplitude is measured by a method described in [3]. Here a BPM is moved and the beam position is measured at 3 BPMs. This has to be done at different BPM positions which results in the sensitivity, see Fig. 4. The mean value of the undulator cavity sensitivity of both transverse planes is $(2.84 \pm 0.01_{\text{stat.}}) \text{ V}/(\text{mm nC})$, expectation is $2.92 \text{ V}/(\text{mm nC})$. The systematic error due to different cable attenuations cause an agreement between measurement results and expectation. Here the TM_{11} field is symmetric to the BPM axis in contrast to the reference resonator.

The voltage as a function of time of the beamline BPM is shown in Fig. 5. The beating is due to higher order modes, that can be seen in the frequency domain in Fig. 5. The first mode is the TM_{11} working mode, but still the other

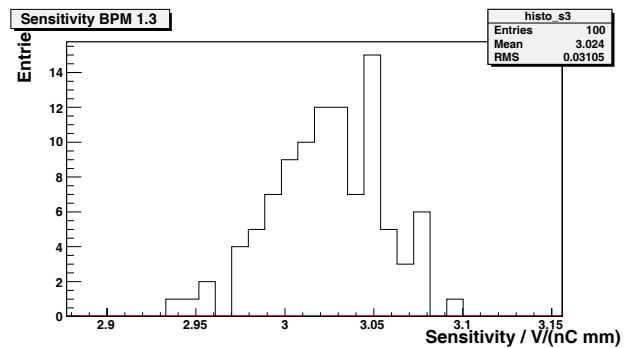


Figure 4: Histogram of the dipole resonator calibration of BPM 1.3.

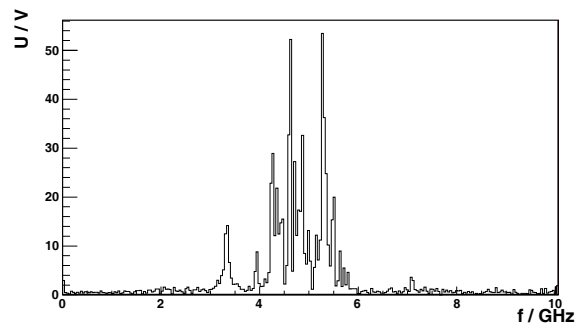
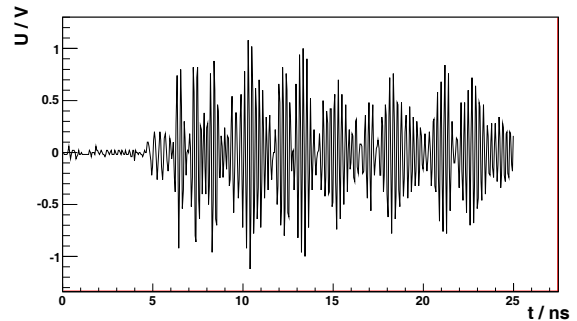


Figure 5: Top: Voltage as a function of time of the beamline cavity BPM. Below: the corresponding signal in frequency domain.

modes transmit through the used low-pass filter (about 5 GHz threshold). Compared to the undulator BPM these modes are closer to the 3.3 GHz working frequency. Therefore the analysis of the beamline BPM for the sensitivity calibration is done in frequency domain and the results are converted to the time domain to be $(1.78 \pm 0.01_{\text{stat.}}) \text{ V}/(\text{mm nC})$. The expected value is $2.03 \text{ V}/(\text{mm nC})$. The lower sensitivity is caused due to the reduction of TM_{11} amplitude compared to the other measured modes. A band-pass filter would improve the signal.

Resolution with Oscilloscope

With the calibration data the position of the beam can be measured. Since all BPMs are in a drift space, two BPMs can be used to calculate the position of the beam at the

third. The residual of several interpolated and measured position shown in Fig. 6 results in a *RMS* values. The sin-

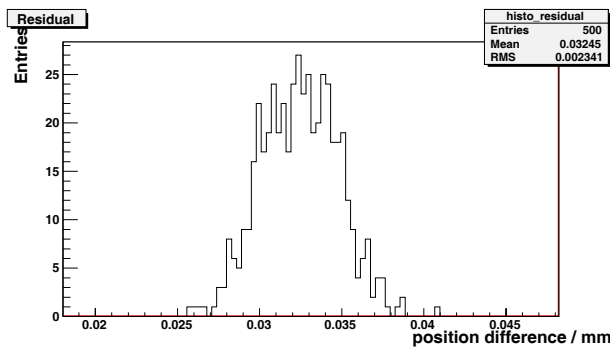


Figure 6: Residual of the resolution measurement of undulator cavity BPMs.

gle resolution R_i of BPM_i can be calculated by using a geometric factor:

$$RMS^2 = \left(\frac{z_{12}}{z_{13}} R_1 \right)^2 + R_2^2 + \left(\frac{z_{23}}{z_{13}} R_3 \right)^2,$$

with z_{ij} the distances between BPM_i to BPM_j . For the undulator BPMs all R_i are equal; with known distances the resolution can be extracted from the *RMS* value. For the beamline BPM resolution the measured undulator BPMs resolutions are taken. In Fig. 7 the resolutions are shown for a charge range between 49 pC to 0.83 nC. In this range

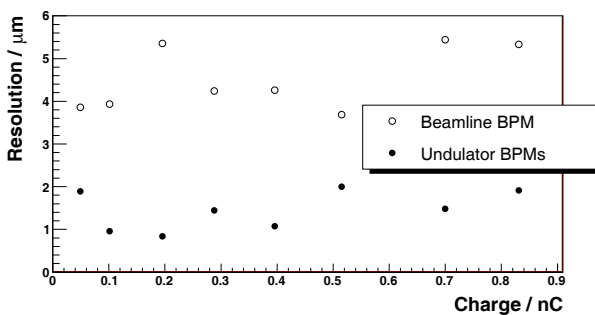


Figure 7: Resolution as a function of charge for undulator and beamline cavity BPM.

there is no degradation of the resolution, since the voltage amplitude range of the oscilloscope was manually adapted. The undulator BPM resolution is better compared to the beamline because of the influence of higher order modes. Nevertheless the desired beamline resolution is better than the specification of $10\mu\text{m}$. The undulator BPMs show a resolution between 0.8 and $2\mu\text{m}$. Specification asks for below $1\mu\text{m}$. The resolution is mainly caused by the 8 bit ADC of the oscilloscope, so improvements with the BPM electronics developed by PSI are expected.

03 Technology

3G Beam Diagnostics

INDUSTRIALIZATION PROCESS; SOME LESSONS TO LEARN

Seventeen undulator and four beamline BPMs prototypes have been produced in advance at different companies. Several difficulties occurred:

- The material has to be annealed such that the resonance diameter does not change after the machining (change the resonance frequency).
- The internal quality factor, determined due to the material, can decrease significantly, if the disks not have a good HF contact. This happened for the reference resonator, when the first brazing joint was several millimeters away from the resonator. Therefore the brazing position was changed close to the resonator.
- By using feedthroughs with higher reflection, e.g. return loss of ≥ -25 dB, the loaded quality of both resonators was changed by about 25%. There is an increase for the reference resonator and a decay for the dipole resonator due to the different modes. Therefore high performance feedthroughs have to be used.
- Measurements of the resonance frequency before brazing the discs of the reference cavity must have a good HF contact, e. g. with pressure, because the resonance frequency depends on the internal quality factor. And the later one is dependent on the conductivity of the resonator walls.
- A difference of the reference resonance frequency of 6 MHz compared to the simulation was determined, caused by the missing symmetry to the BPM axis.

SUMMARY

A BPM test stand is commissioned at FLASH 2010 with an oscilloscope read out. The data were calibrated and the position can be extracted. The measured resolutions almost fulfill the requirement. Significant improvements with the electronics, currently developed, are expected. Care has to be taken for the series production process to receive BPMs within the performances.

ACKNOWLEDGEMENT

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