BEAM POSITION MONITOR CALIBRATION AT THE FLASH LINAC AT DESY

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Abstract

In the FLASH (Free electron LASer in Hamburg) facility at DESY more than 60 BPMs (beam position monitors) with single bunch resolution are currently installed, and more are planned for future installation. Their calibration has been initially made by measuring each electronics board in the RF laboratory. However the ultimate calibration of each monitor is made by measuring its response to beam movement. This is a time-consuming procedure depending on the availability and accuracy of other components of the machine such as steering magnets. On the other hand it has the advantage of getting in one measurement the answer of the monitor with all its components and of being independent of the monitor type. The calibration procedure and particularities for various types of BPMs in various parts of the linac will be discussed. A procedure based on orbit response measurements is also now under study. This would significantly speed up the calibration procedure, which is particularly important in larger accelerators such as the European XFEL (X-ray Free Electron Laser), to be built at DESY.

INTRODUCTION

The FLASH (The Free Electron Laser in Hamburg) facility is a user facility for intense coherent short radiation pulses [1]. The wavelength has been tuned so far in the range from about 13 to 45 nm by varying the energy of the electrons between about 450 and 700 MeV#. FLASH serves also a test facility for the European XFEL (X-ray Free Electron Laser), to be built in Hamburg [2], as well as for the ILC (International Linear Collider) [3].

Fig. 1 shows schematically the FLASH facility. A photoelectric gun emits up to 800 bunches spaced by 1 µs or more. The bunch charge is typically between 0.5 and 1 nC. 5 cryo-modules, each containing 8 superconducting TESLA cavities accelerate the beam to 450 to 700 MeV. Two bunch compressors are used to reduce the bunch length. The FEL beam is produced in the undulator divided into 6 sections.

Beam Position Monitors at FLASH

Various types of BPMs (beam position monitors) with single bunch resolution [4] are installed in the various sections of FLASH. They are shown also in Fig. 1. Button-type BPMs are installed in the undulator section and before the first bunch compressor [5,6]. Stripline BPMs, typically built inside quadrupoles, are found in the rest of the warm parts of the machine [5]. Cavity or re-entrant cavity BPMs are mounted in the end of each cryo-module [7,8].

BPM CALIBRATION

The full chain of a typical FLASH BPM is shown in Fig. 2. The signals from two opposite pickups of a BPM (left-right, or up-down) are sent to a BPM electronics board. This delivers a signal for each bunch correlated to the beam offset in the BPM, which is then sampled and digitized by an ADC and sent to the control system. After applying the calibration coefficients, the data is provided to the operators or to other middle layer servers for further calculations.

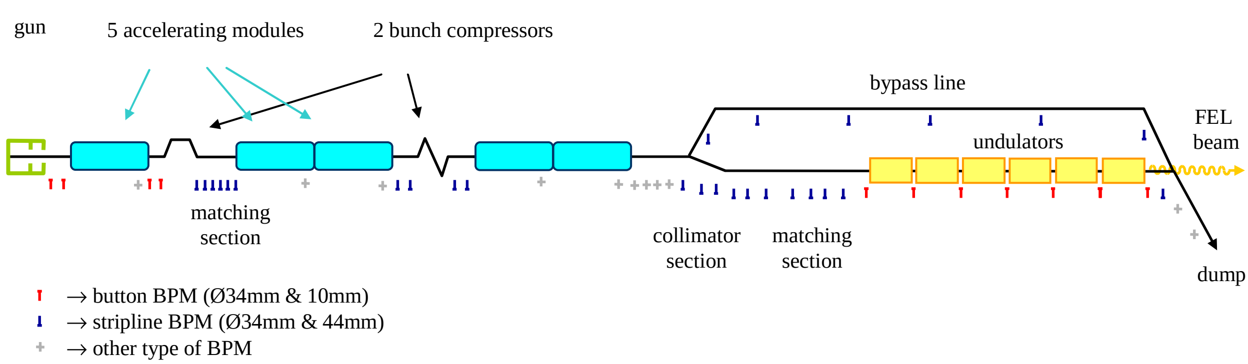

Figure 1: Schematic of the FLASH facility and of the BPM types built in

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1 GeV will be reached after the shutdown in summer 2007, when an additional accelerating module has been built in

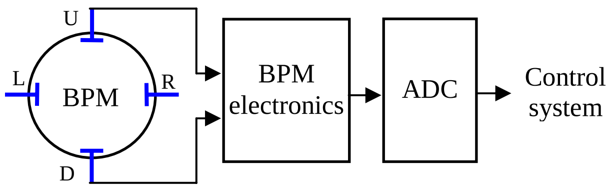

Figure 2: A typical BPM system at FLASH

The signal at one antenna is proportional to [9,10]:

$$F(x,y,\theta) \propto \frac{1}{2}\cdot\int_{\theta-\varphi_0/2}^{\theta+\varphi_0/2}\frac{1-\rho^2}{1+\rho^2-2\rho\cos(\varphi-\alpha)}d\varphi = \arctan\left[\frac{1-\rho}{1+\rho}\cdot\tan\left(\frac{\varphi-\alpha}{2}\right)\right]_{\varphi=\theta-\varphi_0/2}^{\varphi=\theta+\varphi_0/2}, \quad (1)$$

where x and y are the horizontal and vertical beam offsets, $\rho=\sqrt{(x/R)^2+(y/R)^2}$, R is the beam pipe radius, $\alpha=\arctan(y/x)$, and φ_0 is the angle subscribed by each pickup. $\theta = 0$ for the right pickup, $\pi/2$ for the upper, π for the left and $3\pi/2$ for the bottom antenna.

Most FLASH BPMs use so-called TTF2-type electronics. This is based on the AM/PM principle [11,12]. The output of the electronics is proportional to:

$$V_o \propto 2\cdot\arctan\left(\frac{F_R}{F_L}\right)-\frac{\pi}{2}. \quad (2)$$

This signal is proportional to the beam offset in the neighbourhood of the BPM axis, and deviates from this linearity at larger offsets. The linear range for a zero beam offset in the orthogonal plane is roughly 1/3 of the beam pipe. Therefore a linear calibration will provide a good approximation for not so large beam offsets. This is the current method used for the FLASH BPM calibration.

General calibration procedure

The initial BPM calibration is based on the measurements of each electronics board on the test bench. For example, for one stripline electronics a slope of 53 mV/dB has been measured. This combined with the monitor constant obtained from electrostatic simulations of 2 dB/mm, and with the theoretical characteristic of the ADC gives a calibration parameter of about 0.001. This calibration has the disadvantage of not taking into account the small errors in the monitor constant and of the individual ADCs.

A method which takes into account the whole BPM system is the calibration with beam. In this case one uses a magnetic steerer in front of the BPM to change the beam position. In order to avoid errors in quadrupoles and other magnets, situated between the steerer and the BPM, these were switched off after being cycled, in order to avoid remnant fields.

An example of a calibration measurement is shown in Fig. 3. The relative beam position at the BPM is calculated from the steerer current and strength, displayed on the abscissa. The BPM reading is plotted on the ordinate. The slope of the linear part of the curve gives a correction factor of the calibration parameter. For the example above the calibration parameter is in this way determined to be 0.000939.

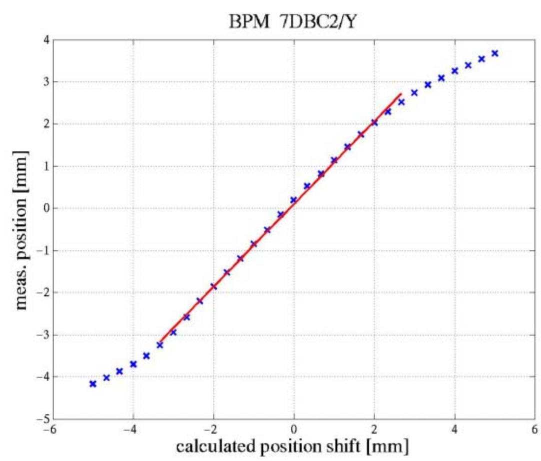

Figure 3: Calibration measurement of a BPM.

Calibration of the BPM offset

For the calibration of the BPM offset, a zero beam offset is simulated with help of a carefully built splitter. The signal from one pickup is split and sent to the two inputs of the electronics. The offset calibration coefficient is then adjusted for zero reading. This method also takes into account possible offsets in all the BPM sub-system.

Calibration of the BPMs in the undulator area

In the undulator section the calculation of the relative beam position is made difficult by dipole fields. Therefore wire scanners with a good position calibration are used as reference for the BPMs, for both the slope and the offset.

Study on Calibration based on Orbit Response Measurements

The BPM calibration at FLASH is presently a lengthy procedure. Therefore we are currently studying a faster method based on orbit response measurements (ORM). With this method, the settings of all magnetic steerers are changed one by one and the orbit response at the BPMs is used to calibrate them. Steerer miscalibrations and optic imperfections can be also found using this method.

Fig. 4 shows a calibration measurement for one BPM. Five steerers have been used to change the beam position. It can be seen that the responses of the BPM to 4 steerers are consistent to each other, while the other one gives a different reading. This implies a miscalibration of this steerer.

The preliminary results are promising. Ultimately, a general method would analyze together optic errors, steerer imperfections and BPM calibration errors.

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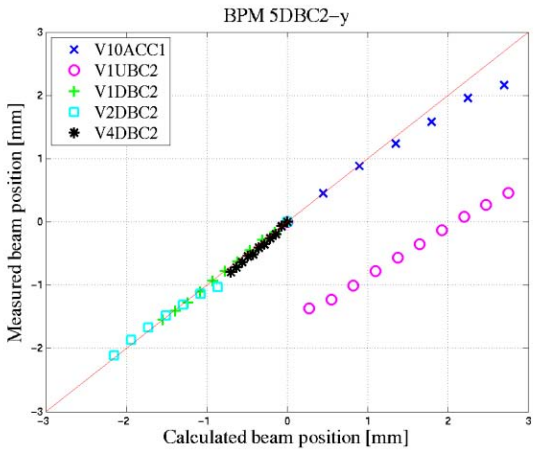

Figure 4: Calibration measurement based on the calculation of the orbit response matrix.

Calibration of the XFEL BPMs

The ORM-based BPM calibration is particularly interesting for larger accelerators such as the European XFEL.

For the offset calibration one can use a test pulse. This pulse can be used parasitically between the beam pulses to measure the properties of the cables, combiner and electronics.

One difficulty with the TTF2-type electronics is that different channels may have different drifts. At the Delay Multiplex Single Path Technique (Neumann Principle), intended to be used with cold button pickups in the cryo-modules [13], both pulses of the two opposite BPM pickups are lined up by a delay line and are transported and processed in the same channel. Gain drifts in the channel (transmission lines and electronics) affect both pulses in the same way and therefore have no impact on position reading. However the drifts of delay line and combiner still influence the position reading.

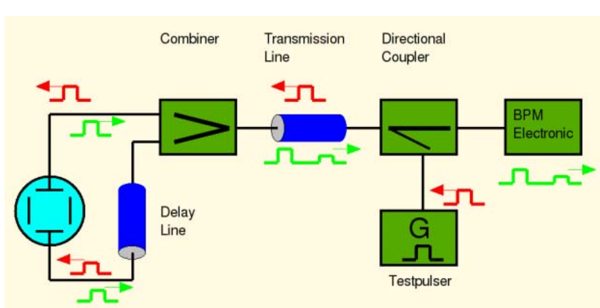

Figure 5: Proposed offset calibration setup for the cold BPMs at the European XFEL.

An offset calibration scheme is proposed in Fig. 5. The test pulses are coupled into the signal path near the readout electronics with a directional coupler. They travel through transmission cable, combiner and delay line to the pickups. There the pulses are reflected and travel back to the readout electronics. Due to the delay line the received signal consists of two pulses with different amplitudes. The voltage ratio is a measure for the attenuation asymmetry and from it one can calculate the offset of the BPM system.

SUMMARY AND OUTLOOK

Each FLASH BPM is currently calibrated individually by measuring its response to beam movement induced by an upstream steerer. In this way the whole BPM chain is taken into account, but it is affected by imperfections of the magnets. An alternative method based on ORM allows averaging such imperfections. Also several BPMs can be calibrated from one measurement. This method is currently under investigation. ORM is a candidate for the XFEL, where the large amount of BPMs makes it more difficult the individual calibration of each BPM.

A 2D calibration is also currently under study, based either on lookup tables or on approximate formulas. This takes into account the different calibration parameter for non-zero offset in the orthogonal plane and the non-linearity for large beam offsets.

The BPM offset is usually calibrated by simulating a zero beam offset with a splitter. Also the offset calibration based on a beam based alignment method is under investigation. This method will enable a more precise determination not of the BPM centre, but of the optical axis of the machine as it is determined by the quadrupoles. At the XFEL the offset of each BPM can be determined and its drift monitored with a test pulse used between the beam pulses.

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