PROPERTIES OF X-RAY BEAM POSITION MONITORS AT THE SWISS LIGHT SOURCE

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Abstract

Tungsten blade type X-ray beam position monitors (XBPMs) are widely used at the SLS to stabilize the photon beam position at the micron level. Various slow (≈ 0.5 Hz) XBPM feedbacks being an integral part of the global orbit feedback system have been in operation for several years [1]. They are solely based on one XBPM reading assuming that the photon beam movement is dominated by angle changes of the electron beam. This paper reports on the operation of the first XBPM feedback using two XBPMs, which allows the separation of positional and angular variations of the electron beam. Correlations between the electron beam movement and the XBPM readings are extensively analyzed in order to disentangle systematic errors of the position determination and real orbit motion. Methods are presented on how to recognize and correct or even avoid large systematic errors of the XBPMs. With this knowledge, the demanding requirements on XBPM accuracy in case of a SPBPF utilizing two XBPMs could be fulfilled for the first time at the SLS.

INTRODUCTION

Spatial beam stability at 3rd generation synchrotron light sources is one of the key ingredients for high precision experiments at the beamlines. Therefore, different feedbacks have been implemented at the SLS. The Fast Orbit Feedback (FOFB) is a global feedback that corrects the electron orbit to a given reference of the Radio Frequency Beam Position Monitors (RF-BPMs) [2]. The Filling Pattern Feedback (FPFB) keeps a constant filling pattern during top-up operation and thus avoids current dependent electronic effects of the RF-BPMs [3]. XBPM feedbacks finally correct for the residual electronic and mechanical drifts of the RF-BPMs by redefining the reference positions, to which the FOFB regulates.

This paper focuses on the XBPMs of the dipole beamline X07DB at the SLS. In contrast to other beamlines with successfully running XBPM feedbacks, not only one but two XBPMs are used to determine both angle and position of the beam. Consequently, the demands on accuracy of the XBPMs are much higher. The arrangement of the XBPMs in a distance of 4.1 m for SPM1 and 6.1 m for SPM2 enhances the effects of reading errors due to the small distance between the XBPMs and the big lever arm from SPM1 to the source point of the photon beam.

CONCEPTS

Auto-Calibration with Staggered Pair Monitors: One approach to estimate the real beam position at an XBPM from single blades b_i is using asymmetries of blade pairs, $a_{13} = (b_1 - b_3)/(b_1 + b_3)$ and $a_{24} = (b_2 - b_4)/(b_2 + b_4)$. In Staggered Pair Monitors (SPMs), which are the kind of XBPMs described in this paper, these blade pairs are vertically staggered from the center by an offset of $\pm\Delta$ (Fig. 1). This geometry is favorable if only vertical beam positions are calculated. The designated position estimator P_{a} is:

$$P_{\mathrm{a}} = k_f \frac{a_{13} + a_{24}}{a_{13} - a_{24}} \cdot \Delta \qquad (1)$$

with $k_f \equiv 1$ assuming $P_{\mathrm{a}} = c \cdot a_{13} + \Delta = c \cdot a_{24} - \Delta$, where c is a constant. SPMs are thus auto-calibrating [4].

Asymmetries are used as well for other types of XBPMs. However, these monitors always need a calibration since the blades are arranged differently to calculate both horizontal and vertical beam positions [5].

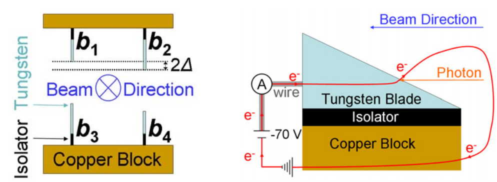

Figure 1: Arrangement of the blades b_i in a Staggered Pair Monitor (left) and circuit diagram of a blade (right).

Single Blade Concepts: For a validation of the SPMs it is vital to determine the standard deviation of the evaluated beam position. Using the single blades as independent monitors leads to four positions P_i $(i = 1, \ldots, 4)$ per SPM. Large systematic deviations of P_i are avoided by normalizing the blade currents b_i with the storage ring current I, $b_i^* = b_i/I$, so that $P_i = k_i b_i^*$ with four individual calibration factors k_i. Thus, the arithmetic mean $P_{\overline{x}}$ can be used as an estimator for the beam position and the standard deviation is evaluated with s_x:

$$P_{\overline{x}} = \frac{1}{n}\sum_{i=1}^{n} P_i \quad , \quad s_x^2 = \frac{1}{n-1}\sum_{i=1}^{n}(P_i - P_{\overline{x}})^2 \qquad (2)$$

Thereby, n is the number of blades ($n = 4$). A generally applicable robust alternative to Eq. 2 is given by the so called median and an according error analysis [6]. However, in well-founded cases it can be justified to exclude single blades a priori to get more reliable results. A reduced arithmetic mean and a standard deviation are calculated with the remaining blades in analogy to Eq. 2.

In this paper, the reduced arithmetic mean of P_1 and P_3, $P_{13} = \frac{1}{2}(P_1 + P_3)$ is used once.

AUTO-CALIBRATION TESTS

In order to test the auto-calibration of the SPMs, the photon beam position was changed in a well-defined way by changing the electron orbit. Considering geometrical and optical properties of the experimental setup, the positional change at the SPMs can be determined from the specified reference positions at the RF-BPMs, to which the electron beam is nearly instantaneously steered by the FOFB. Comparing the model expected positions with the measured readings, values for k_f between 0.94 and 1.08 are usually derived for SPM1, which is sufficiently consistent with the assumption of an auto-calibration (Table 1).

	Dec. 05	Dec. 06	**Feb. 07**		Mar. 07
angular	1.03	1.08	0.99	**7.2**	1.02
positional	0.94	0.97	0.95	**2.4**	0.97

Table 1: Calibration factors k_f, calculated from angular and positional orbit deflections. Highlighted values (Feb. 07) were measured during the first hours after a beam loss in the sector of X07DB, which increased the temperature of the blades for a few minutes by 0.5^{o}C and caused a short-time worsening of the vacuum pressure.

Further tests with coupled positional and angular deflections were performed since "angular" and "positional" values for k_f are slightly different. Fig. 2 shows that a superposed constant angle changes k_f calculated from a positional deflection and vice versa, so that the auto-calibration is only valid in a very limited range. Additionally, horizontal deflections change the readings as if they caused vertical beam motion (Fig. 3). Simulations with realistic alignment and strength errors of magnets can not explain these effects. The coupling between the horizontal and the vertical plane is corrected by the FOFB since it keeps the references at the RF-BPMs constant in both planes. Signal cuts from possible shadowing were not found. The influence of beam dynamical aspects on the photon beam profile will be part of further investigations with an Ionization Profile Monitor [7], which is under construction at the SLS. The tails of the photon distribution, which are detected by the present SPMs, might be understood better consequently.

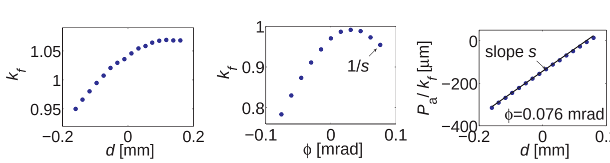

Figure 2: k_f calculated from angular deflections as a function of a superposed constant positional shift d (left) and k_f from positional shifts as a function of a superposed constant angle ϕ (middle). The slope s of the fitting curve (right) determines the marked value $(1/s)$ in the middle plot. (Fitting errors are within point size.)

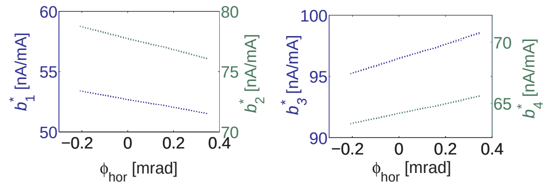

Figure 3: Blade signals of SPM1 as a function of an angular horizontal deflection $\phi_{\rm hor}$. The signal differences correspond to a pretended vertical beam movement of $\approx 40\ \mu$m.

The described dependencies of the SPM readings show that they do not provide an absolute beam position. Nevertheless, relative position changes are clear enough in a small range around a given working point for using them in an SPM feedback.

VACUUM PRESSURE DEPENDENCE

Fig. 4 relates the pressure at the vacuum pump between the SPMs of X07DB and the standard deviations according to Eq. 2. The standard deviations revealed that uncertainties of the SPM readings can be accompanied by vacuum pressure changes and usually remain for some hours after the complete recovery of the vacuum pressure. The drift in the standard deviation of SPM2 indicated additional effects in that case (see next section). In a feedback loop, standard deviations can define a threshold above which the readings should not be used in an SPM feedback

At X02DB beamline, which has the same SPM arrangement as X07DB, changes of the SPM readings of 40 μm were found to be correlated to local vacuum peaks. These peaks could mainly be assigned to SPM1. According to first tests, a revision of the screws of SPM1 removed a big part of the vacuum problems and is planned for all SPMs since they are identical in construction [8].

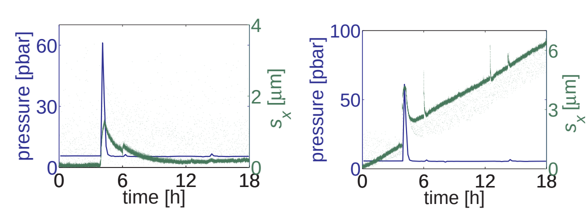

Figure 4: Vacuum pressure at X07DB and standard deviation s_x of SPM1 (left) and SPM2 (right).

SINGLE BLADE EFFECTS

In a first run at X07DB, the SPM feedback drove the references of the adjacent RF-BPMs, which are located 1.4 m before and after the source point of the photon beam, to $\approx$90 μm and $\approx$40 μm respectively, which lead to a $\approx$30 μm steering of the photon beam at SPM2 but only of a few micron at SPM1. These non realistic settings had their main source in the decay of one particular blade signal (SPM2 b_4) when the blades were illuminated again after some time without any light exposure (Fig. 5). Because of the behavior of this blade the estimation of the real beam position with P_a (Eq. 1) was corrupted. As b_2^* showed similar behavior as b_4^* after a few months, the estimation of the beam position at SPM2 was subsequently only based on b_1^* and b_3^* within the SPM feedback loop, using P_{13} to estimate the position at SPM2 (next section). An advantage of the additional exclusion of b_2 was the consequent equal weight of upper blades (b_1, b_2) and lower ones (b_3, b_4), whereby some systematic effects are cancelled. Equal weights are most important during electron injections, as the normalization of b_i with I is not sufficient there. This shows up in the plots of Fig. 4 and 5 as a branch of "outlying" data points.

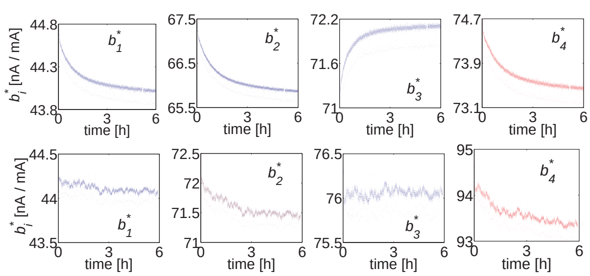

Figure 5: Signals of SPM2 during the first run of the SPM feedback (first row). The beam was driven towards b_3, b_4, so that b_1^*, b_2^* decreased and b_3^* increased. The used estimator P_a was kept constant by the SPM feedback (Nov. 06). The second row depicts blade signals after a renewed illumination without SPM feedback in Jul. 07. b_2^* developed a similar "sick" behavior as b_4^*.

Slowing the Degradation of the Blades: One reason for the degradation of the SPMs is the formation of carbon films on the surfaces of the blades and the isolators. It would therefore be desirable to reduce the attraction of the blades for highly reactive cationic carbon species (carbocations). This could in principle be achieved by a positive or at least less negative bias voltage (presently -70 V). Tests at X02DB with bias voltages from -200 V to +30 V showed that the reaction of the SPMs on position changes was not much different between -200 V and -15 V. A positive influence of a large negative bias on space charge effects or cross talks is not evident. For 0 V and -3 V however, the signals of all blades were lower and could even be negative. A position estimation based on P_a would therefore be critical due to a potential division by zero (see Eq. 1). Nevertheless, the single blade currents showed a sufficiently linear dependence on position changes. Position estimation according to Eq. 2 is uncritical. Due to spikes in the readings, a clear determination of the beam position was not possible with a positive bias voltage.

FEEDBACK OPERATION

Using P_a to estimate the position at SPM1 and P_{13} for SPM2, the SPM feedback successfully corrected the higher beam variation during an outage of the Filling Pattern Feedback (FPFB) (Fig. 6). The seven periods of successive bunch refilling instead of an FPFB regulated injection showed up mainly in additional angular correction by the SPM feedback.

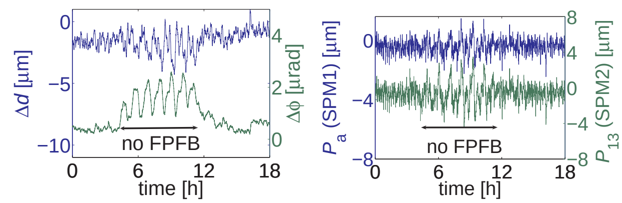

Figure 6: Positional and angular correction Δd and $\Delta\phi$ of the SPM feedback (left) and the beam position at the SPMs according to the used position estimators P_a and P_{13} (right). Due to the SPM feedback correction of about 7 μm at SPM1 and 11 μm at SPM2 during the outage of the FPFB, the RMS deviations only increased from 0.4 μm to 0.6 μm at SPM1 (P_a) and from 0.9 μm to 1.6 μm for SPM2 (P_{13}). The Sampling frequency was 1 Hz.

CONCLUSION

The results of the present investigations show that a successful operation of the SPMs is possible under well defined conditions and performing careful monitoring. The recent improvement of the SPMs concerning their vacuum properties and a revision of the alloyed blades have reduced or eliminated some important systematic errors.

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