FIRST STEPS TOWARDS THE INTEGRATION OF PHOTON BEAM POSITION MONITOR SIGNALS INTO THE SLS FAST ORBIT FEEDBACK

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Abstract

So far, photon beam position monitor (PBPM) signals at the SLS are mainly used to verify the performance of the fast orbit feedback (FOFB), which is based on RF BPM position readings. Additionally, a slow high level PBPM feedback compensates systematic effects of the digital BPM electronics. The development of a new PBPM signal processing electronics allows the synchronization of the PBPM signals with the 4 kHz sampling rate of the FOFB. Subsequent integration of the photon beam position data into the FOFB system will be achieved by signal distribution through fibre optics links (Rocket I/O) based on the generic VME PMC carrier board (VPC) and on mezzanine receiver modules on the FOFB DSP board. The integration of PBPM signals based on the new electronics concept is explained.

INTRODUCTION

User operation of the SLS requires the reproduction and stabilization of a defined reference orbit within 1/10th of the electron beam size. In addition, the growing number of insertion devices (IDs) with their needs to change the gaps transparently to all other users and the increasing sensitivity of the experiments demanded a fast orbit feedback system (FOFB) to stabilize the beam to the required level. Such a FOFB has been foreseen at the design stage of the SLS [1] to correct orbit perturbations in the relevant frequency range up to 100 Hz to provide μm orbit stability. After the commissioning phase [2] the FOFB has replaced the former high level based slow orbit feedback in November 2003. Table 1 summarizes the improvements of the beam stability at the SLS with the FOFB running compared to the situation without feedback. The values still contain the noise contribution of the DBPM system, which has been measured to be $<$0.13 μm within the bandwidth up to 100 Hz.

Table 1: Integrated beam position temporal rms values with FOFB off and on measured at the tune BPM. The values are normalized to the beta function $\beta_{x/y}$ $\approx$12/17 m and reflect the situation for fixed ID settings.

	horizontal		vertical	
FOFB	**off**	**on**	**off**	**on**
1−100 Hz	0.83 μm	0.38 μm	0.40 μm	0.27 μm
100−150 Hz	0.08 μm	0.17 μm	0.06 μm	0.11 μm
1−150 Hz	0.83 μm	0.41 μm	0.41 μm	0.29 μm

In addition to the digital RF BPMs (DBPM), photon beam position monitors (PBPM) are important tools for beam-line and machine diagnostics. Several PBPMs have been installed and commissioned at the SLS [3]. They feature high resolution in the range of 0.5 μm rms ($<$0.5 Hz bandwidth). Due to the long lever arm PBPMs are excellent devices to judge the electron beam stability at the location of the photon beam source point beyond the resolution of any RF BPM. Moreover, PBPMs measure the photon beam movement and therefore allow to discriminate perturbations caused by the electron beam from those caused along the beam-line up to the experimental station. However, position measurements with PBPMs are subject to systematic effects like background radiation from the bending magnets, changes in the ID radiation spectrum during gap changes (for ID PBPMs) and/or varying PBPMs blade response due to thermal effects. Therefore, these systematics of PBPMs have to be understood for the desired ID settings before any conclusion can be drawn from their readouts. At the SLS, the in-vacuum undulators of two protein crystallography (PX) beam-lines and the wiggler of the material science (MS) beam-line are mostly operated at fixed gap positions. The PBPMs at the mentioned beam-lines are well understood and calibrated.

PBPM FEEDBACK ALGORITHM

If PBPM readouts are calibrated they can be integrated into the global orbit correction scheme. The underlying PBPM feedback algorithm changes the orbit reference of the DBPMs adjacent to the IDs in such a way to keep the photon beam position constant at the PBPMs. If only one PBPM is available, the photon beam position change is compensated by a pure angle variation of the orbit at the source point. Eq. 1 allows to calculate the reference change of the two DBPMs 1 and 2 ($d_1,\ d_2$) adjacent to the ID for a desired reading of the PBPM (see Fig. 1).

$$\begin{pmatrix} d_1 \\ d_2 \end{pmatrix} = \frac{1}{a} \begin{pmatrix} -c_{\alpha_x} \cdot l_1 \\ c'_{\alpha_x} \cdot l_2 \end{pmatrix} \cdot x_1 \qquad (1)$$

The factors c_{α_x}, c'_{α_x} translate the purely geometrical offsets for an asymmetrical bump to the required offsets at the location of the DBPMs for a given optics. In case of two available PBPMs, the corresponding necessary angle and offset change can be calculated according to Eq. 2. Similar as in Eq. 1 the factor c_x allows to map a geometrical transverse shift to the necessary transverse offsets at the DBPMs for a given optics. In both cases, the calculated offset $(d_1,\ d_2)$ is subtracted from the orbit reference of DBPM 1 and 2. The new reference settings are fed into the FOFB loop as new set-points.

$$\begin{pmatrix} d_1 \\ d_2 \end{pmatrix} = \begin{pmatrix} c_{\alpha_x}\frac{l_1}{b} + \frac{c_x}{2} & -c_{\alpha_x}\frac{l_1}{b} + \frac{c_x}{2} \\ -c'_{\alpha_x}\frac{l_2}{b} + \frac{c'_x}{2} & c'_{\alpha_x}\frac{l_2}{b} + \frac{c'_x}{2} \end{pmatrix} \cdot \begin{pmatrix} x_1 \\ x_2 \end{pmatrix} \qquad (2)$$

The PBPM feedback will only be active if gaps are closed and below predefined thresholds. It is foreseen that no user input is required to activate the PBPM feedback. The above mentioned criteria are sufficient to automatically start the feedbacks. The reference position of the PBPM is initialized when the ID gap is closed below the threshold and kept constant for a certain time (∼10 s). Once the reference position is defined it is kept until the gap is raised above the threshold.

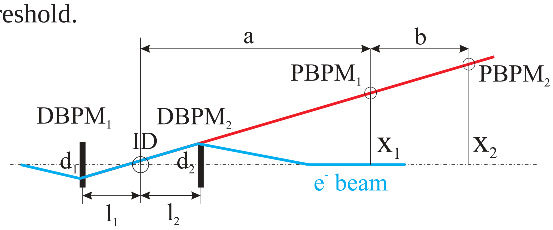

Figure 1: Schematic view of the PBPM and DBPM layout at an ID.

SLOW PBPM FEEDBACK PERFORMANCE

Although the FOFB confines the closed orbit to the reference positions of the involved DBPMs to within less than 1 μm the reference of these BPMs is not perfectly static. The analysis of PBPM data revealed a bunch pattern (intensity) dependence in the RF front-end of the 4-channel DBPM electronics [3]. The implementation of a bunch pattern feedback finally eliminated this effect [4]. Nevertheless remaining systematic effects, like a small temperature dependence of the DBPM electronics in the technical gallery and movements of the DBPM blocks in the storage ring caused by varying heat load on the vacuum chamber or by temperature fluctuations in the SLS tunnel for example due to a beam loss, may still lead to a change of the FOFB reference on the μm level. In order to tackle the problem, presently three slow (≈0.5 Hz bandwidth) feedback loops have been implemented involving PBPMs located at a distance of ≈8.6 m from the IDs of two PX beam-lines featuring in-vacuum undulators and one wiggler based MS beam-line. The feedbacks, which are by default only activated for gaps <8.5 mm in order to minimize the photon beam profile dependence of the PBPM readings, only involve one PBPM according to Eq. 1. Fig. 2 depicts the variation of the horizontal and vertical reference of the upstream DBPM together with the corresponding stabilized PBPM readings at one of the PX beam-lines over ≈85 h of continuous FOFB and "top-up" operation. The resulting temporal distributions of the photon beam positions exhibit rms values of σ_x = 0.37 μm and σ_y = 0.5 μm for frequencies <0.5 Hz.

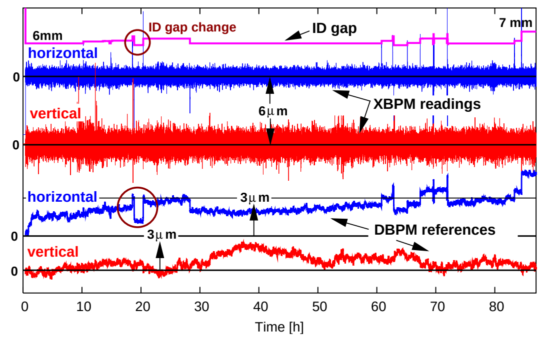

Figure 2: Slow PBPM feedbacks provide sub-μm rms in-loop stability of the PBPM reading at the first optical elements of presently three beam-lines (exemplified by the data taken at a PX beam-line over 85 h of FOFB and "top-up" operation).

FAST PBPM READOUT

Recently the synchronous readout of the PBPM blade photo current at one of the PX beam-lines has been upgraded to 1 kHz using the existing hardware. Although the PBPM readout is not yet synchronized to the DBPM readings it allows to study the performance of the FOFB down to the millisecond range. The presently uncalibrated horizontal and vertical power spectral densities in Fig. 3 document the significant improvement of the photon beam stability up to the 0 dB point with active FOFB. Although

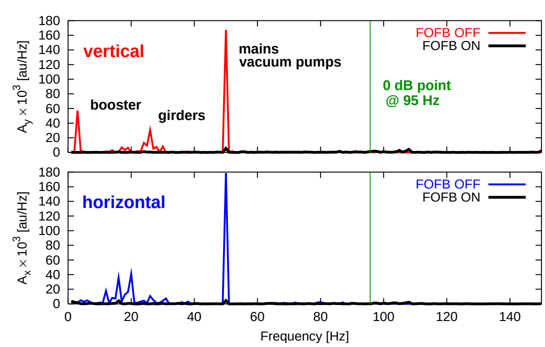

Figure 3: The uncalibrated vertical and horizontal power spectral densities taken at the PBPM of a PX beam-line document the significant improvement of the photon beam stability up to the 0 dB point with active FOFB (black curves).

the preliminary results are still subject to further investigations to clarify the perturbation reduction factors it confirms the successful suppression of perturbations originating from the electron beam which are also seen by DBPMs. As a consequence, it provides the possibility to integrate PBPMs into the global orbit feedback system. This, of course, is only the case for PBPMs at IDs with well defined operation modes and for vertical PBPMs at bending magnet beam-lines.

FOFB UPGRADES

The FOFB will be upgraded for two reasons. Firstly, it will be extended by an additional DBPM in the FEMTO insertion [5] and corresponding adjacent correctors. Secondly, additional interfaces will be implemented to allow the integration of several PBPMs into the FOFB loop.

The extension to include an additional DBPM and horizontal/vertical corrector pair is necessary to provide proper fast beam steering at the entrance of the in-vacuum undulator which is part of the partially completed FEMTO insertion. Adding a DBPM/corrector pair to the present FOFB layout with its 72 DBPMs and 72 correctors in each plane will brake the symmetry. As a consequence it is foreseen to introduce 7 DBPMs/sector in order to maintain the present structure where 11 of them remain "virtual" for the time being.

As a second step it is foreseen to adapt and synchronize the fast PBPM blade current readouts to the DBPM/FOFB sampling rate of 4 kHz. In order to achieve this goal a new current digitizer hardware is under development which will replace the presently used 4-channel low current asymmetry detector. The new electronics is based on the generic VME PMC carrier board (VPC) [6] which will become the standard platform for diagnostic devices at PSI. The clock rate for the PBPM ADCs is derived in the same way as in case of the DBPM system. The main RF frequency of 499.651 MHz is divided by the harmonic number to get the revolution frequency of 1.04 MHz. A further decimation by a factor of 256 will result in the same clock rate as in the FOFB case. Since all clock signals will be derived from the main RF frequency they will be locked to each other. An external trigger input from the timing system will provide the possibility to start the decimation of all PBPMs synchronously to the decimation of the DBPMs. The PBPM electronics will be connected to a Gigabit fibre optic ring (Rocket I/O) network with a dedicated interface to the multi-processor bus on the DBPM/FOFB digital signal processor board (Fig. 4). In this way, several PBPMs can be integrated into the FOFB, which gives the flexibility to include one or two PBPM at each ID and/or PBPMs at the bending magnet beam-lines. The additional position information of the PBPMs will then be available to the FOFB in the same way as it is the case for all DBPMs which are provided as memory mapped readings on the DSP multiprocessor bus.

STATUS AND CONCLUSION

Integration of slow PBPM feedbacks into the FOFB has provided excellent medium term photon beam stability at the position of the first optical elements of the beam-lines. Recent power spectral density measurements with PBPMs have demonstrated that photon monitors are promising candidates to stabilize the photon beam beyond the stability performance obtained by a fast orbit feedback based exclusively on DBPMs. It is therefore foreseen to make PBPM readings directly available to the FOFB.

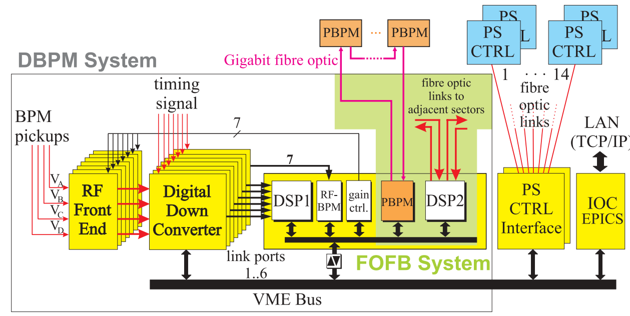

Figure 4: Schematic view of the PBPM integration into the FOFB. An additional interface from the Gigabit fibre optic ring network which connects all PBPMs maps the photon position readings on the DSP multi-processor bus of the present DBPM/FOFB system.

Presently, the DSP interface hardware for the integration of an additional DBPM and for the Gigabit ring network is tested under laboratory conditions. As a first priority, a 7th DBPM will be included into the DBPM system in one of the twelve sectors within the next three months in order to provide the required beam stability in the FEMTO insertion. As soon as the new PBPM readout electronics becomes operational the fibre optic ring connecting all PBPMs in one sector will be closed. Thus, PBPM readings will be available synchronously to all DBPMs at a rate of 4 kHz. As a first step, the three high level PBPM feedbacks for the MS beam-line and for the two PX beam-lines will be implemented in the low level DSP software. These beam-lines operate in well defined modes, the PBPMs are well understood and therefore ideal candidates for testing the integration of PBPMs in the fast global orbit correction scheme. In a second step, new PBPM feedbacks can be added to the FOFB to accommodate the needs of upcoming bending magnet beam-lines and for ID based beam-lines with calibrated PBPMs for a restricted parameter space of the IDs.

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