COMMISSIONING AND OPERATION OF THE SLS FAST ORBIT FEEDBACK

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Abstract

The SLS Fast Orbit Feedback (FOFB) was successfully commissioned in 2003 [1]. Since November 2003 it runs during user operation of the SLS. Taking into account 72 Digital Beam Position Monitors (DBPMs), the FOFB applies SVD-based global orbit corrections for 72 horizontal (x) and 72 vertical (y) correctors at a rate of 4 kHz, compared to $\approx$ 0.5 Hz for the Slow Orbit Feedback (SOFB) that was used so far. While the SOFB was important for the elimination of orbit drifts due to temperature changes and slowly moving insertion device (ID) gaps, the FOFB is also able to damp orbit oscillations that are caused by fast changes of ID gaps or magnets, by ground and girder vibrations, 3 Hz booster crosstalk and power supply noise. This report presents experience from commissioning and user operation of the FOFB.

INTRODUCTION

The Swiss Light Source (SLS) is a third generation synchrotron radiation facility, which is in operation since the mid of 2001. Successful user operation requires the reproduction and stabilization of a previously established reference orbit ("golden orbit") within 1/10th of the electron beam size. In the vertical plane this translates into $<$1 μm at the location of the IDs. The desired angular beam stability is $<$1 μrad, corresponding to $<$10 μm photon beam motion at the first optical elements of the beamlines. During the first two years of SLS operation, the above mentioned stability requirements were achieved by a central high level application, the so-called slow orbit feedback (SOFB), which performed global orbit corrections at an update rate of 0.5 Hz [2]. However, the growing number of beamlines performing fast and independent ID gap-scans as well as the increasing sensitivity of the experiments to orbit distortions caused by ground vibrations and environmental noise required an increase of the orbit correction bandwidth. This has been achieved by commissioning the SLS fast orbit feedback (FOFB) during the year 2003. The FOFB was designed to correct orbit perturbations in a frequency range of up to 100 Hz to a μm level.

FOFB ARCHITECTURE

As a result of the localized structure of the SVD-inverted corrector/BPM response matrix, where only the diagonal and their adjacent coefficients have non-zero values [3], the global SLS FOFB has been implemented in a decentralized architecture. The FOFB is an integral part of the SLS digital BPM (DBPM) system, which is distributed over the 12 sectors of the SLS storage ring. The feedback algorithms are performed in parallel on 12 (local) DSP boards, and BPM data are directly exchanged between adjacent sectors via fast fiber optic links. This structure allows the calculation of the required corrector magnet kicks per sector based on 18 BPM readings of three adjacent sectors at a rate of 4 kHz. The resulting corrector kicks are fed into one PID controller per corrector. The FOFB is initialized and monitored by a central PC-based beam dynamics server, which takes into account the number of available BPMs and correctors. Any off-energy trajectories in the horizontal plane are corrected by the central RF frequency. Since the resulting frequency corrections are carried out by a slow high level application on the central beam dynamics server, dispersion orbits must not be corrected by the FOFB and have to be subtracted before each orbit correction.

FOFB OPERATIONAL EXPERIENCE AND PERFORMANCE

The FOFB has been operational during SLS user shifts since November 2003. The overall reliability of hardware and software has been the main focus during the first phase of operation. Therefore, the FOFB has been operated at moderate PID loop gains and DBPM filter settings, providing a regulation bandwidth of about 60 Hz. In order to avoid beam loss due to possible malfunctioning FOFB components, a low level software security package has been implemented which monitors the parameters of the FOFB and the performance of its subsystems. When exceeding predefined corrector magnets deadbands, the FOFB is automatically stopped and a corresponding alarm is displayed to the operator, who can thus decide to call an expert or to continue with FOFB operation. So far, the FOFB has shown an overall availability of $>$95%. Although some automatic interruptions of FOFB have been caused by malfunctioning of DBPM electronics and corrector magnet power supplies, a growing number of FOFB interruptions are caused by users who perform beamline commissioning during regular user shifts.

Frequencies up to nearly 100 Hz in both transverse planes are damped by the FOFB in its present operation mode. Although the overall loop delay, which has been measured to be approximately 1.6 ms, could not be reduced by a DBPM firmware upgrade, the synchronization of all DBPM electronics allowed the use of a more stringent set of PID parameters, which finally led to the operation of the FOFB close to its design parameters [3]. Fig. 1 shows the measured FOFB closed loop transfer function for both transverse planes. Orbit perturbations up to 100 Hz are effectively damped, while noise sources between 100 and 300 Hz are moderately excited. Similar to other light

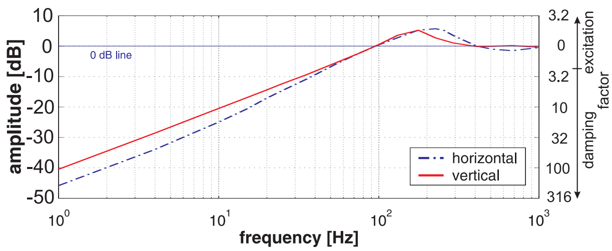

Figure 1: Measurement of FOFB closed loop transfer functions in both transverse planes. Effective damping of orbit perturbations has been achieved close to the FOFB design goal of 100 Hz.

sources, the main orbit perturbations at SLS in the frequency range up to 100 Hz are dominated by booster respectively injector operation (3 Hz), vibrations at the girder eigenmodes (15-30 Hz), and 50 Hz induced by power supply noise and/or asynchronous pumps. Snapshots of the horizontal and vertical power spectral densities and integrated spectral densities with and without FOFB measured at the tune BPM outside the feedback loop are shown in Fig. 2. It can clearly be seen that orbit perturbations caused by the booster, which is in the same tunnel as the storage ring and which is continuously ramped during "top-up" operation of the SLS, as well as girder vibrations are significantly damped. The 50 Hz peaks are still reduced by a factor of 3-5, while noise contributions above 100 Hz are moderately increased. Table 1 summarizes the improvements of

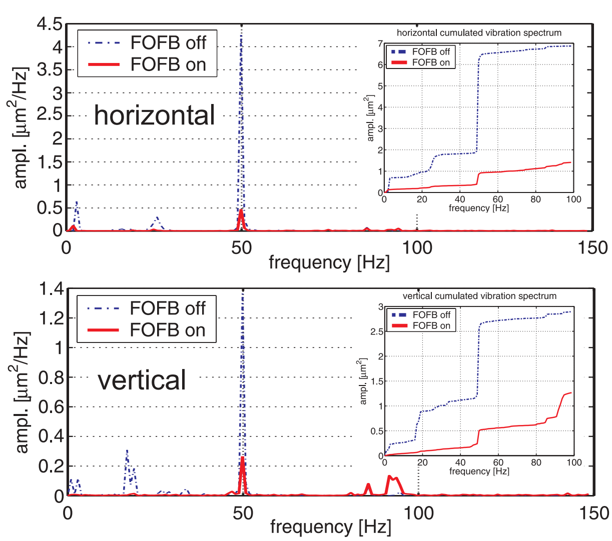

Figure 2: Snapshots of the horizontal and vertical power spectral densities measured at the tune BPM outside the orbit feedback loop. The cumulated power spectral density is shown in the small embedded plots on the right hand side.

beam stability at 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 FOFB bandwidth. Orbit distortions caused by ID gap changes, which lead to severe orbit perturbations when the FOFB is not active, are not included. The temporal RMS values are integrated over the active range of the FOFB (up to 100 Hz) and up to 150 Hz, where significant noise contributions could still be observed. The temporal RMS values at a location s in the storage ring are obtained from the table by multiplication with $\sqrt{\beta(s)}$. At the location of the tune BPM with β_y=18 m (see Fig. 2) this translates into vertical temporal RMS values of σ_y=1.15 μm, while at the source points of the SLS low gap insertion devices (β_y=0.9 m) the integrated vertical beam motion up to 100 Hz is σ_y=0.25 μm. Apart from the improved integrated beam stability up to

Table 1: Integrated beam position temporal RMS values with FOFB off and on at the tune BPM normalized to the beta function, without moving of ID gaps. The respective values at a location s in the storage ring can be obtained by multiplication with $\sqrt{\beta(s)}$.

	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

100 Hz, the FOFB allows autonomous and independent changes of ID gaps as well as beamline optimization by the users. Tests with rapidly moving ID gaps and correctors have shown that the resulting orbit kicks are invisible to all other users when the FOFB is active. Since beam position information in the SLS FOFB architecture is only distributed locally and dispersion fits in each sector are based on a total of 18 beam position readings at a rate of 4 kHz, the low level part of the feedback corrects off-energy trajectories only on a micron level. Resulting slow drifts of the dispersion orbit and horizontal mean corrector kicks are avoided by a high level beam dynamics application, which adds suitable offsets to horizontal corrector currents and RF frequency every 20-30 minutes.

Photon BPM (PBPM) readings have been taken as external references to demonstrate the efficiency of electron beam stabilization for the beamlines. Although the readout of the four PBPM blades are not yet synchronized, preliminary power spectral density measurements of a single PBPM blade have demonstrated the efficient suppression of the photon beam excitation arising from the electron beam oscillations at 3 Hz, at the girder eigen frequencies and at 50 Hz [4].

Presently, a slow high level feedback application based on the PBPM readings provides sub-μm RMS beam stability at the first optical elements of the SLS beamlines. The slow feedback applies an asymmetric bump by changing the reference orbit of the FOFB. Thus, it is a cascaded feedback system. A systematic oscillation with a period of ~45 min showed up on the reference orbit changes. This oscillation was originally suspected to be a temperature effect in the four channel DBPM electronics (Fig. 3). However, measurements of the DBPM rack temperatures only showed a correlation with other systematic long term drifts. Just lately, the time constant of the 45 min oscillation could be correlated to the injection clock cycle, which constantly proceeds over the buckets to be filled in the storage ring during "top-up" operation. A corresponding bunch pattern dependency in the RF front-end of the DBPM electronics has been demonstrated to be the reason for the orbit oscillations. A bunch pattern feedback in the storage ring has been implemented to eliminate this effect [5] (lower plot in Fig. 3). The PBPM signals at SLS are presently still subject

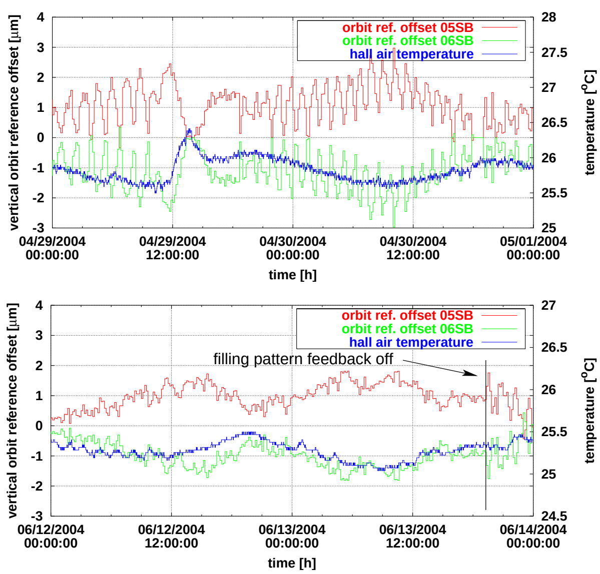

Figure 3: FOFB reference orbit changes of the two RF BPMs (05SB, 06SB) adjacent to the ID. An asymmetric bump is applied by a high level slow feedback in order to keep the photon BPM reading constant. With the filling pattern feedback a 40-50 minute oscillation (upper plot) due to a filling pattern dependence of the BPM system could be eliminated (lower plot). The remaining drift is mainly due to air temperature variations at the location of the BPM electronics.

to position offsets whenever the ID gaps are changed. Fig.4 shows horizontal and vertical photon beam positions at the X06S protein crystallography (PX) beamline over a measurement period of two days. The data points are not (yet) synchronized to the DBPM readings and have been averaged over a period of 1s. In conjunction with the FOFB it stabilizes the photon beam at the location of the PBPMs at 10 m distance from the source point to ±1.5 μm peak to peak.

CONCLUSION AND PERSPECTIVES

The global FOFB with its distributed hardware structure is in regular user operation since November 2003 and has lead to sub-μm electron beam stability at SLS in a frequency range from ∼0.1-100 Hz. Stabilitywise, it has exceeded its original design parameters and satisfies the

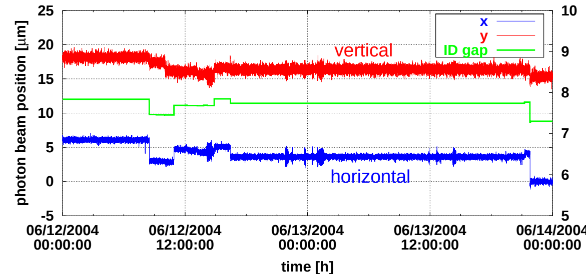

Figure 4: Resulting photon beam position at the X06S protein crystallography (PX) beamline over a period of two days with an active slow high level feedback on top of the FOFB to stabilize the position. The readings have been averaged over a period of 1s. A gap change results in a new reference position for the high level PBPM feedback.

present stability requirements of the SLS users. The regular "top-up" operation of the SLS at presently 330 mA (±0.5 mA) provides most stable and reproducible conditions for the DBPM electronics and leaves the storage ring in a thermal equilibrium. A residual systematic beam oscillation of ±1.5 μm at the location of the photon BPMs has been correlated to the SLS injection cycle clock and has been identified as a filling pattern dependence of the DBPM electronics. A slow, high level feedback application has been implemented at the protein crystallography and material sciences beamlines to correct for these oscillations, stabilizing the photon beam at the location of the first optical elements to a sub-μm level.

The commissioning of the "fs pulse slicing" beamline as well as the construction of additional bending magnet beamlines during the next year will break the symmetry of the present FOFB architecture due to additional RF and photon BPMs, which are needed to provide the required beam stability for these experiments. Therefore, an extension of the FOFB architecture is already foreseen, allowing the integration of fully synchronized position readings from additional sensors on the DSP bus of the FOFB system.

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