COMMISSIONING AND OPERATION OF THE SLS FAST ORBIT FEEDBACK

T. Schilcher, M. Böge, B. Keil, P. Pollet, V. Schlott

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 [2]. 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

Successful user operation of the SLS 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 $\approx 1\ \mu$m at the location of the IDs. The desired angular beam stability is $< 1\ \mu$rad, corresponding to $< 10\ \mu$m photon beam motion at the first optical elements of the beam-lines, about 10 m downstream from the radiation source point. During the first two years of SLS operation, these requirements were achieved by a central high level application, the Slow Orbit Feedback (SOFB), with an update rate of $\approx$ 0.5 Hz. However, in 2003 the growing number of IDs with fast gap scans and the increasing sensitivity of the experiments at the SLS as well as orbit oscillations by ground vibrations and environmental noise required stabilization by a fast orbit feedback. The FOFB was designed to correct orbit perturbations in the relevant frequency range up to 100 Hz to μm stability using the singular value decomposition (SVD) method in order to guarantee the necessary beam stability.

FOFB ARCHITECTURE

In contrast to the centralized PC-based SOFB, the FOFB performs the feedback algorithm in parallel on 12 DSP boards. The diagonal structure of the SVD-inverted corrector/BPM response matrix allows a decentralization of the feedback algorithm although it is still a global orbit correction scheme. The Fast Orbit Feedback is an integral part of the Digital BPM system (DBPM) which is distributed over 12 sectors. Each BPM station handles six BPMs and controls six corrector magnets in both transverse planes (Fig. 1). Adjacent BPM/feedback sectors are directly connected via fast fiber optic links. This allows the calculation of the required corrector magnet kicks per sector based on 18 beam positions at a rate of 4 kHz. The resulting corrector kicks are fed into one PID controller per corrector. A central PC-based beam dynamics server initializes and monitors the FOFB, taking into account the number of available BPMs and correctors. The central RF frequency is used as an additional control parameter to correct off-energy trajectories. Frequency corrections are carried out by a high level slow feedback application on the beam dynamics server. Dispersion orbits must not be corrected by the FOFB and are therefore subtracted before each orbit correction.

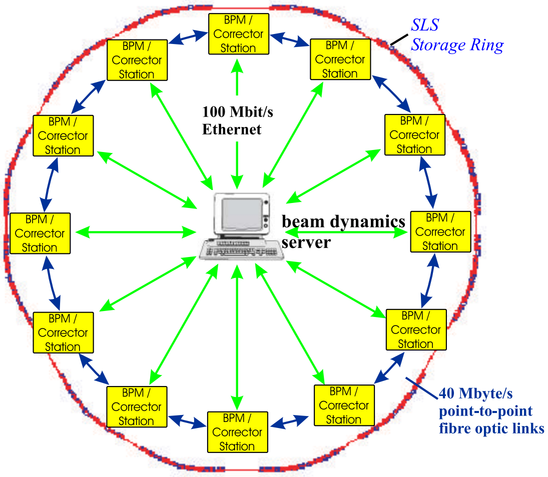

Fig. 1: Fast Orbit Feedback (FOFB) layout. The feedback is decentralized and integrated in the twelve BPM/corrector stations. A dedicated fiber optic network provides communication between adjacent sectors. A central beam dynamics server initializes and monitors the FOFB.

PERFORMANCE AND OPERATION RESULTS

Since middle of November 2003 the FOFB is operational full-time during SLS user shifts. During the first phase of operation the focus was on the overall reliability of hardware and software rather than on ultimate performance. Therefore the FOFB was operated with moderate PID loop gains and DBPM filter settings. In addition, limitations of the present DBPM firmware result in an overall loop delay in the order of 1.6 ms [1]. Nevertheless, this allows damping of orbit perturbations up to 60 Hz vertically and 55 Hz horizontally. The measured vertical closed loop transfer function is shown in Fig. 2 which reveals the capability of the FOFB to damp undesired orbit oscillations within the important frequency range. The PID feedback loop reduces perturbations up to 60 Hz for the present configuration of the FOFB and may excite the electron beam between 60 and 300 Hz. Fig. 3 shows that the FOFB damps os-

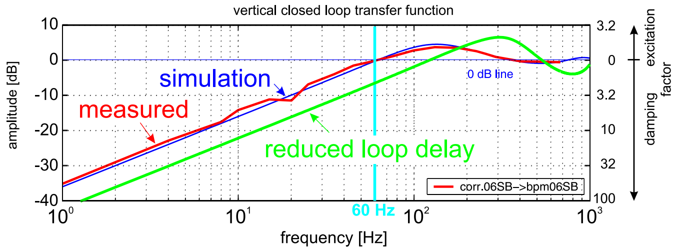

Fig. 2: Measured and simulated closed loop FOFB transfer function in the vertical plane for moderate PID loop gains. The amplitude curve shows that the FOFB suppresses orbit perturbations below 60 Hz. Reducing the loop delay by upgrading the DBPM hardware gives the possibility to increase the feedback bandwidth to 100 Hz.

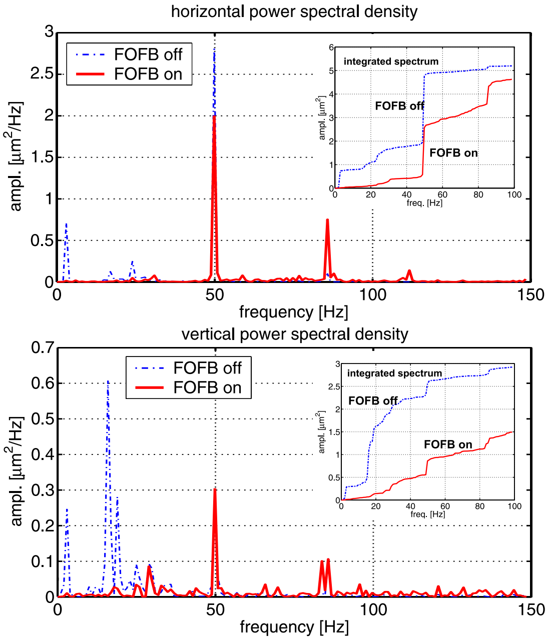

Fig. 3: Snapshots of the horizontal and vertical power spectral density at the tune BPM, with Fast Orbit Feedback off and on. The 3 Hz noise caused by the booster, which is in the same tunnel as the storage ring, and the beam excitation at the girder eigenmodes (15-30 Hz) are significantly damped. The present bandwidth of the feedback system is 55 Hz horizontally and 60 Hz vertically.

	horizontal		vertical	
FOFB	**off**	**on**	**off**	**on**
1-60 Hz	0.7 μm	0.5 μm	0.35 μm	0.25 μm
60-150 Hz	0.2 μm	0.45 μm	0.15 μm	0.25 μm
1-150 Hz	0.75 μm	0.7 μm	0.4 μm	0.35 μm

Table 1: Integrated beam position temporal RMS values with FOFB off and on, without moving ID gaps, normalized to β_x=β_y=1 m.

cillations caused by 3 Hz booster noise and 16-26 Hz girder vibrations significantly. The cause of the 85 Hz line in the spectrum has not been identified yet. Table 1 shows the beam stability improvements of the FOFB up to 150 Hz, measured at the tune BPM outside of the feedback loop. The temporal RMS values are normalized to the beta function and still contain the noise of the DBPM system. The RMS values for FOFB switched off do not include orbit distortions by ID gap changes which would even more emphasize the capability of the FOFB. The temporal RMS value at a location s is obtained from the table data by multiplication with $\sqrt{\beta(s)}$. This translates into temporal RMS values of σ_y=1.5 μm at the tune BPM (β_y = 18 m) and σ_y=0.3 μm at the source point of ID 6 (β_y = 0.9 m). Tests with rapidly moving ID gaps and correctors showed that the resulting orbit kicks were invisible at all other IDs when the FOFB was running, i.e. the FOFB completely decouples the IDs from each other. This is also clearly visible in the long term behavior of the FOFB during user operation (Fig. 4). Here, each data point represents the spatial RMS value of all 72 BPMs in the feedback loop with respect to the pre-defined "Golden Orbit". Furthermore, the BPM readings are averaged over a period of 0.32 ms. While RF frequency corrections and ID gap changes resulted in global orbit distortions on a time scale of several seconds in case of the SOFB, these orbit transients are no longer visible with the FOFB. Since local dispersion fits in each sector are based on only 18 beam positions at a rate of 4 kHz, the low level part of the feedback corrects off-energy trajectories on the sub-micron level. In order to avoid resulting slow drifts of the dispersion orbit and horizontal mean corrector kick, a high level beam dynamics application adds suitable offsets to horizontal corrector currents and RF frequency every few seconds. This results in a blurred distribution of the global horizontal spatial RMS (see upper right plot in Fig. 4). However, the ID straight sections are dispersion free and thus not affected by this horizontal drift. The FOFB has stabilized the electron beam on average to $x(rms) \approx 0.71\ \mu m$ horizontally and $y(rms) \approx 0.06\ \mu m$ vertically with respect to the 72 RF BPM readings.

The most important criteria for the efficiency of electron beam stabilization are the residual fluctuations of the photon beam along the beam-lines. X-ray beam position monitors (XBPM) with four blades have been used for photon beam stability measurements [3]. These monitors deliver an independent cross check of electron beam oscillations in addition to RF BPM measurements. Since the present configuration of the XBPM electronics does not allow a sufficiently synchronous readout of all four blades, horizontal and vertical vibration spectra are not available yet. Nevertheless, the power spectral density of a single blade already provides information about the photon beam oscillations. A snapshot of two spectra with FOFB off and on is shown in Fig. 5. The XBPM spectrum is very similar to the tune BPM spectrum (Fig. 3). The effect of the FOFB is clearly visible in the frequency range up to 60 Hz where photon beam excitations at 3 Hz and at the girder eigenmodes are significantly damped. Similar measurements at all other XBPMs of the SLS have confirmed this result.

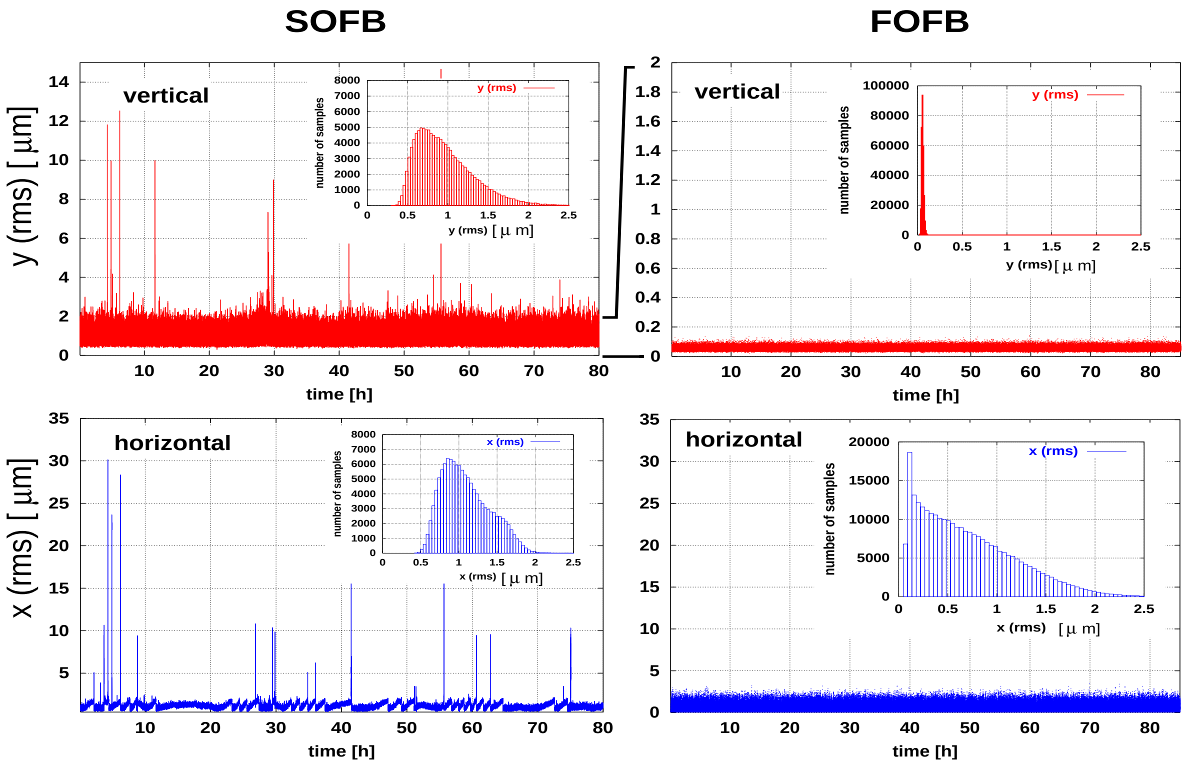

Fig. 4: Horizontal and vertical spatial RMS orbit of 72 in-loop BPMs with respect to the “Golden Orbit”. Each data point is based on averaged BPM data over a period of 0.32 s. Both columns show the long term performance of the slow and fast orbit feedback respectively over a period of three days. Orbit distortions due to RF frequency and ID gap changes (spikes in the RMS orbit) are completely ruled out by the FOFB. The mean value of the spatial RMS orbit with FOFB is $x(RMS) \approx 0.71\ \mu m$ horizontally and $y(RMS) \approx 0.06\ \mu m$ vertically.

CONCLUSION AND PERSPECTIVES

It was shown that FOFB is vital to guarantee photon beam stability at all SLS beam-lines in a frequency range up to 100 Hz. Although the FOFB achieved excellent orbit stability and already has exceeded some design requirements, further improvements are possible, e.g. an increase of the FOFB bandwidth to its design goal by reducing the loop delay. This can be achieved by a DBPM firmware upgrade that synchronizes the data transfer between all 72 DBPMs, by accelerating the data transfer from the feedback electronic to power supplies, and by further improvements of filter settings in the Digital BPM system using non-linear phase response filters. Remaining drifts of the photon beam [3] could be correlated with temperature oscillations in the cooling water. Compensation schemes for these systematic effects are presently being investigated. One of the possible solutions is the implementation of an additional slow feedback that adjusts the FOFB reference orbit so that the photon beam positions remain constant. This has already been demonstrated successfully at the protein crystallography beam-line [3]. The above mentioned systematic oscillations of the photon beam with periods of about 30 minutes could be eliminated from its initial peak-to-peak values of 8 μm corresponding to sub-micron drifts at the photon source point. Finally, the FOFB may also be used to localize and thus to minimize or eliminate avoidable sources of residual orbit oscillations.

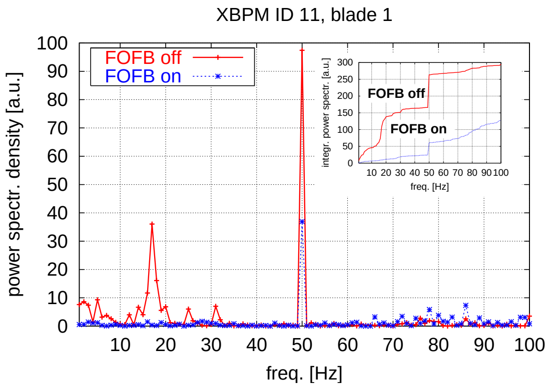

Fig. 5: Snapshots of the power spectral density and integrated spectral density of one of the XBPM blades (at insertion device 11) indicating the transverse motion of the photon beam.

REFERENCES

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