COMMISSIONING OF THE FAST ORBIT FEEDBACK AT SLS

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Abstract

At the SLS a Fast Orbit Feedback (FOFB) has been designed to stabilize the closed orbit to the 1 μm level up to frequencies of 100 Hz. The feedback is integrated into the digital BPM system [1] by means of 12 dedicated digital signal processors (DSP) and a fiber optic network. Submatrices of the "inverted" corrector/BPM response matrix are distributed to the BPM stations and corrections are performed in parallel. First promising commissioning results of the FOFB running at 4 kHz orbit sampling rate are presented. It is demonstrated that the chosen FOFB concept is appropriate and has the potential to reach or even exceed the design goals.

INTRODUCTION

Orbit stability and reproducibility of the electron beam at the location of the radiation source points is a crucial requirement at the Swiss Light Source. It is desirable to suppress the photon beam fluctuations by at least one order of magnitude below the spot size at the experiments. At the SLS this translates into electron beam angular stability along the insertion device straights below 1 μrad and into beam position stability below 1/10th of the vertical beam size which corresponds to $\approx$ 1 μm. A Slow Orbit Feedback (SOFB) working with less than 1 Hz correction rate is in operation since August 2001 and succeeded to stabilize the orbit in both planes to 1 μm RMS [2]. At the low beta short straight insertion devices the electron beam oscillations could even be reduced to a sub-micron level of $\sigma_{x/y} \approx 0.5$ μm. Measurements of the power spectral densities at the tune BPM have shown that the main contributions to orbit perturbations lie in a frequency range below 100 Hz (see Tab. 1). Integration up to 100 Hz results in beam motions of 0.5 $\mu\mathrm{m}/\sqrt{\mathrm{m}}$ horizontally and 0.4 $\mu\mathrm{m}/\sqrt{\mathrm{m}}$ vertically (normalized to the beta function) without any fast feedback. The average machine beta values for the SLS storage ring are $\beta_{x/y} \approx$ 10 m at the locations of the BPMs. The residual beam motion caused by sources given in Tab. 1 as well as additional orbit perturbations introduced by an increasing number of insertion devices (ID) and experimental stations require stabilization by a fast orbit feedback.

Frequency	Noise Source	RMS contribution horizontal	vertical
3 Hz	booster ramp	0.5 μm	0.35 μm
20-35 Hz	girder eigen frequencies	0.85 μm	1.4 μm
50 Hz	line frequency, vacuum pumps (async.)	1.2 μm	0.45 μm
85 Hz	unidentified		0.35 μm

Table 1: Main contributions to orbit oscillations at SLS without feedback measured at the location of the tune BPM with $\beta_x \simeq 11$ m and $\beta_y \simeq 18$ m. The quadratic sum of the contributions yields a RMS value of 1.6 μm horizontally and 1.55 μm vertically.

FOFB IMPLEMENTATION

General Layout

The layout of the SLS FOFB is based on the structure of the "inverted" beam response matrix where only the diagonal and their adjacent coefficients have non zero values. Therefore, steerer magnet settings are only determined by position readings from their closest BPMs [3]. As a result, the feedback calculations can be decentralized allowing to implement the FOFB throughout the twelve BPM stations. Each of the twelve stations handles six direct BPM inputs and six corrector magnet outputs. The data between adjacent BPM stations are transmitted over a fiber optic point-to-point network which reflects the localized structure of the "inverted" beam response matrix.

Integration Issues

Basis for the FOFB is the real time operation mode of the digital BPM (DBPM) system where each BPM electronics continuously delivers data at a rate of 4 kHz. This rate is the result of down conversion and decimation in the digital receivers with their 31.2 MHz ADC clocks locked to the 500 MHz ring RF frequency. Presently, the 4 kHz data streams of the 72 digital BPMs are not synchronous to each other. Thus, the FOFB has to wait for the latest data acquisition before a new orbit correction can be calculated although the transfer time for BPM data between the different sectors takes only 8 μs. The asynchronous data rate introduces an additional delay of maximal one feedback cycle which amounts to 250 μs. This delay will be eliminated by a DBPM firmware upgrade. The passband width of each BPM is set to 2 kHz by means of programmable filters on the digital receiver. It results in a resolution of 1.2 μm and typical group delays of about 300-600 μs. The numerical controlled oscillator (NCO) frequencies on the DDCs are adjusted to the main RF frequency. An automatic loop on the BPM low level control system tracks the ring RF frequency and reprograms the NCO frequencies to keep the BPM signal in the passband width of the DDCs. This becomes important when even smaller passband widths of the BPMs are envisaged in order to reduce noise and group delays in the DDCs and hence to increase the bandwidth of the feedback loop. Frequency changes are necessary since horizontal path length effects are taken into account by the FOFB as well. Off-energy orbits are not corrected by the steerer magnets but by adjustments of the RF frequency. It is therefore necessary to subtract the dispersion orbit from the measured orbit before a correction is applied. The dispersion orbit is extracted on the DSP level by a one dimensional SVD fit on the position data from three sectors, which corresponds to 18 BPM readings. Whenever the fitted RF frequency error exceeds 5 Hz (equivalent to dP/P$\sim 2 \cdot 10^{-5}$) a high level application on the beam dynamics model server [4] corrects the RF frequency.

The start of the fast orbit feedback is performed in a sequence where the central high level orbit correction application (former 'slow orbit feedback, SOFB') corrects the electron beam to the required reference orbit within 5 μm and adjusts the RF frequency. Subsequently, all necessary feedback parameters including the inverted response submatrices and PID control parameters are downloaded to the DSPs at the twelve BPM stations. A global trigger from the timing system starts the FOFB on all BPM stations synchronously. Since the same number of correctors and BPMs are used to constrain the orbit to the "Golden Orbit" at each of the 72 BPM locations, it is indispensable to rely on each single position reading. BPM pickup cross checks of the four RF buttons have therefore been implemented on the DSP in order to detect BPMs with spurious bad readings. If the sums of the two diagonal BPM button raw values do not agree within a predefined level (default 20%) the reading is considered to be faulty. In such a case, the DSP disables the BPM and stops the feedback in this particular sector because the structure of the "inverted" response submatrices are not appropriate anymore. The halt of the feedback loop on one BPM station also directly affects the two adjacent sectors which do not get position readings over the fiber links anymore and consequently skip the correction cycles with 'data timeouts'. The localized structure of the fast orbit feedback allows this type of asymmetric operation mode. Nevertheless the feedback is then automatically stopped by the EPICS control system which permanently monitors the status of all sectors. The high level orbit control application reloads a new set of sub-matrices where the particular faulty BPM is disabled and finally restarts the feedback. This scenario has already been successfully tested during machine development shifts.

Feedback Characterization

Besides the different components in the feedback loop like corrector magnets, vacuum chambers, BPM system and global BPM data distribution, the overall performance of the feedback system depends on the type of the digital controller. Presently, a simple PID controller has been implemented. The horizontal and vertical open loop transfer functions from a corrector magnet to its closest BPM (nearly no phase advance) have been measured (see Fig. 1) in order to optimize the feedback parameters. The underlying model of the fitted data comprises a first order low pass filter representing DDC filters, corrector magnet, vacuum chamber and eddy currents, a fifth order low pass filter for the digital power supplies and a time delay for the digital processing. The fit predicts first order low pass bandwidths of $\approx$ 355 Hz horizontally and $\approx$ 830 Hz vertically indicating the asymmetry of the SLS storage ring vacuum chamber. Independent laboratory measurements of the digital power supplies showed a fifth order low pass filter characteristics with a small signal bandwidth [5] of 2 kHz. Delay times through the digital processing chain were determined to $\approx$ 300 μs for the digital receivers, $\approx$ 60 μs for the first DSP for beam position calculations, $\approx$ 70 μs for the feedback algorithm in the second DSP and $<$ 160 μs to transfer the correction values to the power supplies. A maximum of 250 μs have to be accounted for the global data exchange due to the asynchronous transfer. Therefore a total digital time delay of around 700 μs corresponding to 3 correction cycles were used in the fit.

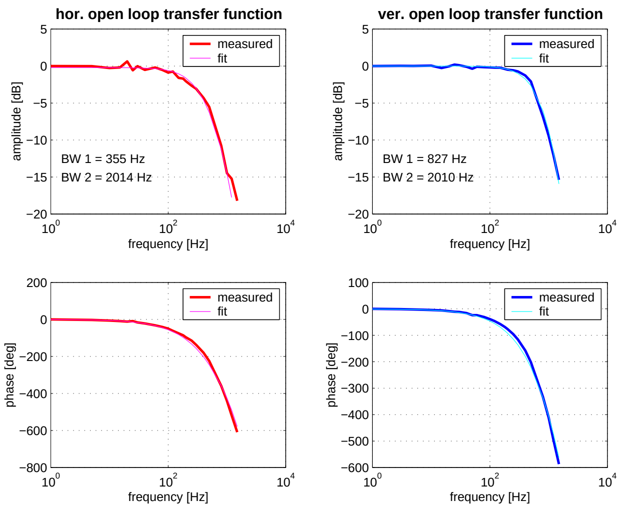

Figure 1: Horizontal and vertical open loop transfer functions of the fast orbit feedback. The model of the fit consists of a series of a first (bandwidth 1) and fifth order (bandwidth 2) low pass filters and a time delay.

RESULTS

Up to now, the FOFB was operated only during machine development shifts. The tune BPM has been chosen for monitoring the FOFB performance since it is not part of the feedback loop and therefore allows a more objective analysis of beam oscillations. Although the observed orbit excitations vary over time, Tab. 1 gives an overview of the main beam noise sources and their typical contributions to the position RMS value at the location of the tune BPM. Note, the beta functions at this BPM amount to $\beta_x \simeq 11$ m and $\beta_y \simeq 18$ m while the average machine beta values are $\beta_{x/y} \approx 10$ m at the location of the BPMs. The measured power spectral densities of both planes (see Fig. 2) show snapshots of the orbit excitations at the tune BPM with and without feedback. The dominant noise sources in the frequency range up to 100 Hz as indicated in Tab. 1 could be suppressed from 1.7 μm to 1.4 μm horizontally and from 1.5 μm to 0.9 μm vertically. Fig. 3 shows the measured vertical closed loop transfer function for non-optimized PI start parameters. The differential control has not been applied so far. According to the transfer function unity gain is reached at 80 Hz and moderate amplifications can be observed up to 400 Hz. The integrated RMS orbit motions were enlarged from 0.95 μm to 1.1 μm horizontally and from 0.95 μm to 1.2 μm vertically.

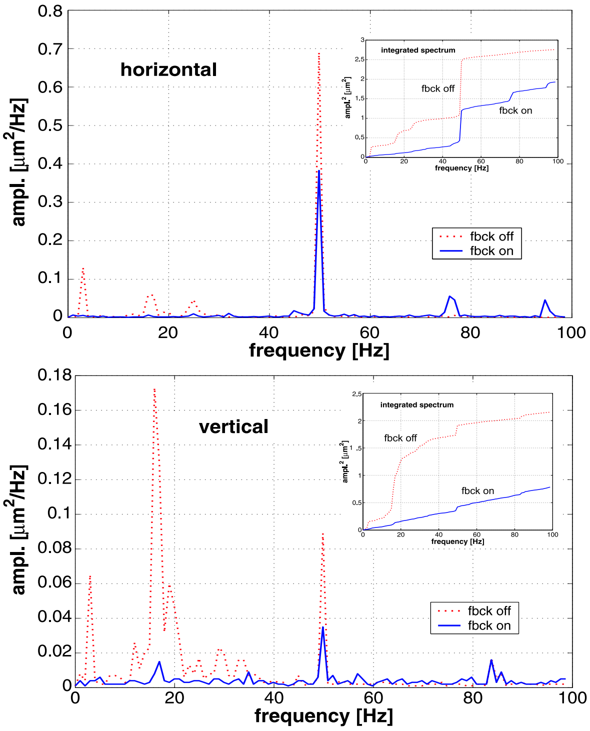

Figure 2: Snapshots of the horizontal and vertical power spectral densities measured with the digital BPM system at the location of the tune BPM.

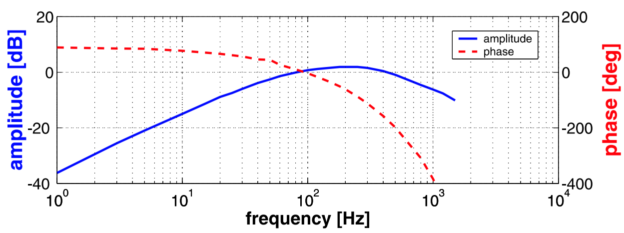

Figure 3: Measured vertical closed loop transfer function with moderate PI parameter settings. The amplitude curve shows the maximal suppression of orbit perturbations at the locations of the BPMs.

Two excitation of the electron beam at frequencies of 76 and 95 Hz are most likely due to numerical rounding errors in the digital receivers. This effect can be eliminated by adjusting the internal gain settings in the DBPM system. The integrated position RMS values with and without feedback are summarized in Tab. 2.

	horizontal		vertical	
FOFB	**off**	**on**	**off**	**on**
0.5-100 Hz*	1.7 μm	1.4 μm	1.5 μm	0.9 μm
100-400 Hz*	0.95 μm	1.1 μm	0.95 μm	1.2 μm

Table 2: Integrated position RMS values at the location of the tune BPM ($\beta_x \simeq 11$ m, $\beta_y \simeq 18$ m).

*These figures still contain the sensor noise contribution which is not clearly quantified yet.

CONCLUSION AND PERSPECTIVES

The commissioning of the SLS FOFB has just started and first results have been presented. Its conceptional design could be successfully demonstrated. Focus during the first measurements was the commissioning of the feedback components rather than optimization of the performance.

To reach the FOFB design goals of integrated sub-micron orbit stability up to 100 Hz in both planes, several improvements will be accomplished during the further commissioning. An upgrade of the DDC firmware to synchronize the 4 kHz BPM outputs will reduce the digital feedback delay by 240 μs. Beside this, the data transfer from the DSP to the power supply controller which presently takes place via the IOC of the control system will be short cut. Both upgrades will reduce the digital latency and consequently increase the loop bandwidth. Optimizations of PID parameters are required to achieve increased feedback performance. Recent laboratory studies have shown the potential to reduce the BPM noise clearly below 1 μm even at 2 kHz bandwidth. Furthermore, long term and power spectral densities measurements at several locations especially close to the insertion devices as well as X-ray BPM measurements will be necessary in order to quantify the residual position RMS values of the orbit.

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