USER OPERATION AND UPGRADES OF THE FAST ORBIT FEEDBACK AT THE SLS

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Abstract

A report on the performance of the fast orbit feedback (FOFB) in its 2nd year of user operation is given. Photon beam position monitors (XBPM) have been included by means of a slow feedback which changes the reference settings of the FOFB. Users are permitted to change the XBPM references within certain limits while the feedback is running. A fast synchronous readout of the XBPMs allows their integration into the FOFB loop. The FOFB will be extended by an additional beam position monitor (BPM) in order to satisfy the requirements of the upcoming FEMTO project.

INTRODUCTION

Successful user operation of the SLS requires the reproduction and stabilization of a previously established reference orbit within 1/10th of the electron beam size. In the vertical plane this translates into $\approx$1 μm at the location of the insertion devices (IDs) in the short straight sections. The corresponding required 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 these requirements were achieved by a central CORBA based high level application [1], the Slow Orbit Feedback (SOFB), with an update rate of $\approx$0.5 Hz [2]. However, in 2003 the growing number of IDs with fast gap scans and the increasing sensitivity of the experiments as well as orbit oscillations induced by ground vibrations and environmental noise necessitated stabilization by the envisaged global fast orbit feedback (FOFB). The FOFB was designed [3] to correct orbit perturbations in the relevant frequency range up to 100 Hz to μm stability.

ARCHITECTURE

In contrast to the centralized PC-based SOFB, the FOFB runs 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 which nevertheless realizes a global orbit correction scheme. The FOFB is an integral part of the Digital BPM system (DBPM) [4] which is distributed over 12 sectors. Each BPM sector handles 6 DBPMs and controls 6 correctors in both transverse planes (Fig. 1). Adjacent BPM sectors are directly connected via fast fiber optic links. This allows the calculation of the required corrector kicks per sector based on 18 beam positions at a rate of 4 kHz. The resulting kicks are fed into one PID controller per corrector. The SOFB running on 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 orbits. Frequency corrections are carried out by the SOFB. Dispersion orbits must not be corrected by the FOFB and are therefore subtracted before each correction step. Due to the localized FOFB structure 12 independent dispersion fits on 18 beam positions are performed. This deficiency in turn leads to a gradual build-up of a dispersion related horizontal corrector pattern with a nonzero mean which is periodically corrected by the otherwise passive SOFB.

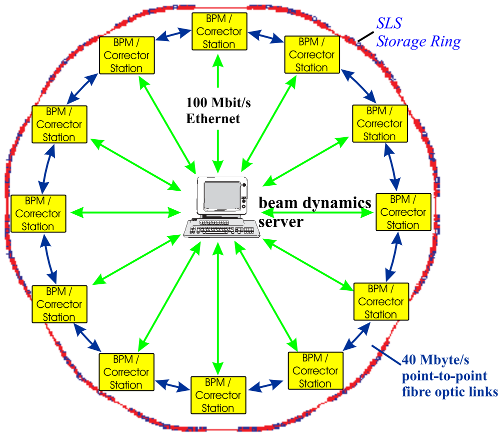

Figure 1: The Fast Orbit Feedback (FOFB) is integrated in the 12 BPM/corrector sectors. A dedicated fiber optic network provides communication between adjacent sectors.

USER OPERATION

The Fast Orbit Feedback (FOFB) is running in user operation 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 $\approx$60 Hz [5]. In order to avoid beam loss due to possibly 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. If corrector magnets exceed predefined dead bands after initialization by a SOFB based orbit correction to RMS difference orbits of $<$5 μm, the FOFB is automatically stopped and resumed only on operator intervention. The FOFB has shown an overall availability of $\approx$98%. Although some interruptions of the FOFB have been caused by malfunctioning DBPM electronics ($\approx$1 failure/month), corrector magnet power supplies and the control system including the operator (1−3 failures/month), a growing number of FOFB interruptions is caused by users which perform beamline commissioning work during user operation.

Frequencies up to ≈100 Hz in both transverse planes are attenuated by the FOFB in its present mode of operation [6]. Although the overall loop delay of ≈1.5 ms could not be reduced by a recent DBPM firmware upgrade, the global synchronization of the DBPM electronics over the 12 sectors allowed the use of a more stringent set of PID parameters, which finally led to a operation mode of the FOFB close to its design parameters [3]. In this mode orbit perturbations up to 95 Hz (0 dB point) are attenuated , while noise sources between 95 Hz and 300 Hz are moderately excited. Damping factors of ≈100 at 2 Hz (most critical for ID gap induced motion) and ≈4−5 at 50 Hz have been achieved. It should be mentioned that the orbit excitation spectrum in the frequency range 80−100 Hz does not contain any dominant lines. A remaining problem are intermittent "RF glitches" of ≈30 ms length which have been observed on RF frequency changes introduced via the IEEE interface of the RF generator. The resulting off-energy orbits of ≈300 μm at DBPMs with large horizontal dispersion are picked up by the FOFB. Fortunately corrections occur rarely (<1/h) whenever the SOFB predicted frequency change exceeds 5 Hz. Tab. 1 summarizes the improvements on 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 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 RMS values at a location s in the storage ring are obtained from the table by multiplication with $\sqrt{\beta_{x/y}(s)}$. At the source points of the low gap IDs in the short straight sections with β_y ≈0.9 m this translates to vertical RMS values of σ_y = 0.25 μm integrated up to 100 Hz. Apart from the improved integrated beam stability up to 100 Hz, the FOFB allows autonomous changes of ID gaps as well as transparent optimization of all beamlines at the same time since the effect of rapidly moving ID gaps and correctors in the vicinity of these IDs has been proven to be invisible to the other beamlines if the FOFB is running. Since the FOFB uses the SVD-inverted 72x72 corrector/BPM response matrix without any eigenvalue cut-off for correction, it can follow "arbitrary" reference orbit changes within the limits of the available corrector strength. In this case orbit steering for a beamline translates to a change of the orbit references of two DBPMs upstream and downstream of the ID. Due to the large FOFB damping factors at low frequencies operator induced reference modifications appear to be established instantaneously. It also allows the simple implementation of slow (up to a few Hz) XBPM based feedbacks which are discussed in the following section.

Table 1: Integrated beam position temporal RMS values with FOFB off and on at the tune BPM normalized to the beta function $\beta_{x/y}$ ≈12/17 m for fixed ID gaps.

	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

XBPM FEEDBACKS

The presented excellent stability within the FOFB loop confines the closed orbit to the reference positions of the involved DBPMs to within less than 1 μm. Unfortunately the reference of these BPMs is not perfectly static. Separate BPMs (e.g. "Tune DBPM") and XBPMs are very well suited to independently judge the resulting orbit stability at the photon source points. The analysis of these data revealed a systematic oscillation of the photon beam with slowly changing periodicity (≈45 min) [7]. This effect was originally suspected to be a temperature effect in the 4-channel DBPM electronics but could be finally traced back to the injection clock cycle, which constantly sweeps over the buckets selected for injection during "top-up" operation. A corresponding bunch pattern (intensity) dependence in the RF front-end of the DBPM electronics turned out to be the reason for the orbit oscillations. The implementation of a bunch pattern feedback finally eliminated this effect [8].

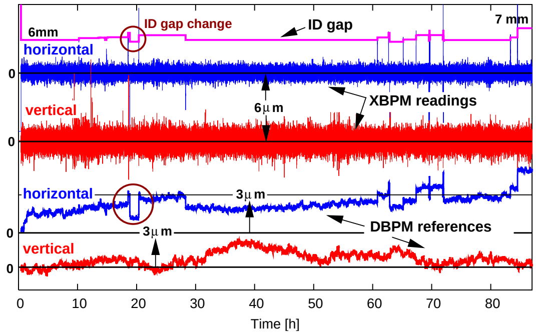

Figure 2: Slow XBPM feedbacks provide sub-μm RMS photon beam stability at the first optical elements of presently three beamlines (exemplified by the data taken at a PX beamline over 85 h of FOFB and "top-up" operation).

Nevertheless air temperature variations at the location of the DBPM system electronics in the technical gallery together with temperature fluctuations in the SLS tunnel for example due to a beam loss 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 XBPMs located at a distance of ≈8.6 m from the IDs of two protein crystallography (PX) beamlines featuring in-vacuum undulators and one wiggler based material science (MS) beam-

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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 XBPM readings, translate the photon beam position change to a pure angle variation of the orbit at the source point and change the reference of the DBPMs adjacent to the IDs in the FOFB loop accordingly (cascaded feedback scheme). Fig. 2 depicts the variation of the horizontal and vertical reference of the upstream DBPM together with the corresponding stabilized XBPM readings at one of the PX beamlines over ≈85 h of continuous FOFB and "top-up" operation. The resulting temporal distributions of the photon beam positions exhibit 2nd moments of σ_x = 0.37 μm and σ_y = 0.5 μm for frequencies <0.5 Hz. Fig. 3 visualizes a change of the upstream vertical DBPM reference by ≈ -15 μm in case of a beam current drop from 350 to 250 mA (≈0.15 μm/mA) while the reference XBPM position at the MS beamline was kept constant by the XBPM feedback. This example underlines the necessity to maintain a constant heat load on the involved accelerator and beamline components as they exhibit temperature dependencies (see "thermal" in Fig. 3) which together with current dependencies of the DBPM electronics give rise to the observed dramatic reference change. Since the beam current of 350 mA was restored after 4 h the measurement allowed to determine the characteristic time constant τ = 1.7 h for reestablishing thermal equilibrium.

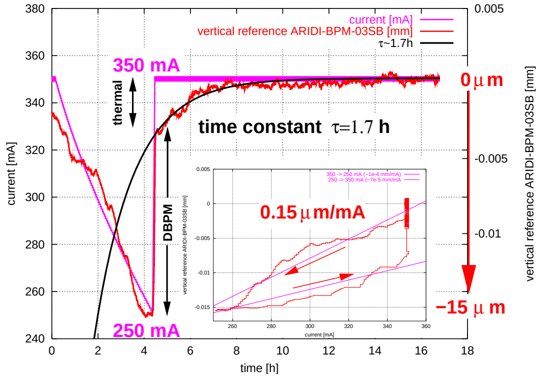

Figure 3: The upstream vertical DBPM reference (red curve) changed by ≈ -15 μm in case of a beam current (magenta curve) drop from 350 to 250 mA (≈0.15 μm/mA) while the corresponding XBPM position at the MS beamline was kept constant by the XBPM feedback.

UPGRADES

The FOFB will be extended by an additional DBPM and corresponding adjacent correctors in order to provide proper fast beam steering at the entrance of the in-vacuum undulator which is part of the partially completed FEMTO insertion [9]. In addition to the different corrector magnet design the system integration is of concern since the symmetry of the FOFB layout is broken. 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. Recently the synchronous readout of the XBPM blade currents at one of the PX beamlines has been improved to 1 kHz using the existing hardware. The presently uncalibrated horizontal and vertical spectral densities in Fig. 4 document the significant improvement of the photon beam stability up to the 0 dB point with FOFB on. The "DBPM peak" at 185 Hz with FOFB on was introduced by a faulty RF front-end of an adjacent DBPM. In the near future all XBPMs will be equipped with readout electronics which will allow their integration into the FOFB loop.

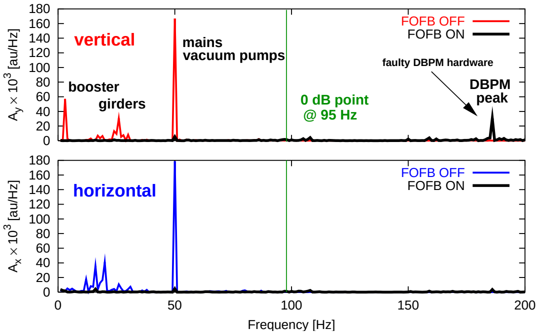

Figure 4: The uncalibrated vertical and horizontal spectral densities taken at the XBPM of a PX beamline document the significant improvement of the photon beam stability up to the 0 dB point with FOFB on (Courtesy: J. Krempaský).

CONCLUSION

The FOFB has reached or even exceeded the original design parameters [3] in its 2nd year of user operation at an availability of ≈98%. It will be extended by at least one DBPM and most probably several XBPMs in the near future. Excellent medium term stability can only be achieved in conjunction with "top-up" operation [10].

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