IDENTIFICATION OF SOURCES OF ORBITAL DISTORTIONS IN CORRECTOR SPACE

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Abstract

Since modern ring and linear accelerator based light sources feature fast orbit feedback (FOFB) systems, which transform orbital distortions in beam position monitor (BPM) space into corrector space over a wide frequency range, most perturbations can be directly analyzed utilizing the corrector pattern. In corrector space the localization of sources of distortions is facilitated since the large (per unit phase) number of BPMs and correctors involved provides good spatial resolution. Applications of this technique include the Beam-Assisted Girder Alignment (BAGA) where changes in the corrector pattern are interactively analyzed while girder positions are remotely altered or the Beam-Based Alignment (BBA) of quadrupole/BPM pairs where the variation of corrector values as the result of quadrupole variations are observed. In both cases large oscillations in BPM space are completely surpressed by the FOFB leading to well controlled and stable conditions during the measurement.

INTRODUCTION

The "instantaneous" transformation of orbital distortions in Beam Position Monitor (BPM) space into corrector space requires a performant Fast Orbit Feedback (FOFB) system with a sufficient gain over a large frequency range. The use of such a system for measurements also demands a high degree of reliability. For this reason the design/implementation and present performance of the Fast Orbit Feedback (FOFB) at the SLS is recapitulated. It is followed by a description of two measurement procedures namely the Beam-Assisted Girder Alignment (BAGA) and the Beam-Based Alignment (BBA) of BPM/quadrupole pairs, which both rely on a running FOFB and demonstrate the potential of the presented technique.

FAST ORBIT FEEDBACK (FOFB)

During the first two years of SLS operation the orbit stability requirements were achieved by a central high level application [1], the Slow Orbit Feedback (SOFB), with an update rate of ≈0.5 Hz [2]. However 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 a global fast orbit feedback (FOFB). The FOFB was designed [3] to correct orbit perturbations in the relevant frequency range up to 100 Hz to sub-μm stability in this range. 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 is capable of handling 6(+1) DBPMs and controlling 6(+1) 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. Figure 2 depicts the present FOFB performance (damping factor) as a function of frequency. Unity damping is reached at ≈95 Hz. At low frequencies the damping factor increases to a value >100 [5].

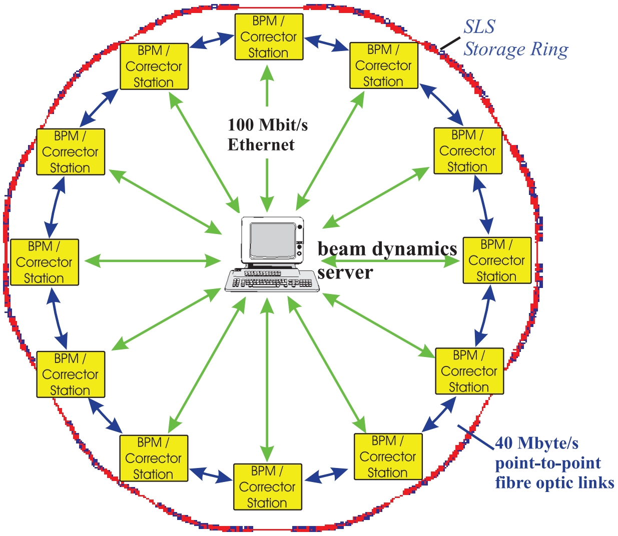

Figure 1: The Fast Orbit Feedback (FOFB) is integrated in the 12 BPM/corrector sectors. A dedicated fiber optic network provides communication between adjacent sectors.

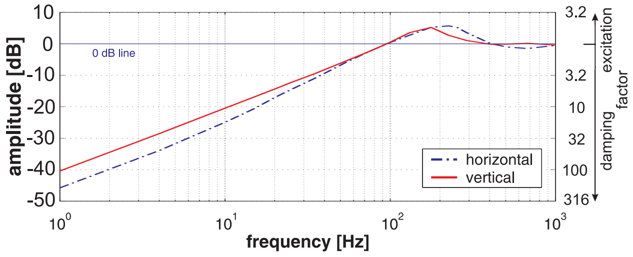

Figure 2: Present FOFB performance (gain and damping/excitation factor) as a function of frequency.

Although the FOFB was designed 15 years ago it still fulfills the SLS operational stability requirements. Nevertheless new digital BPM electronics is presently under development at PSI [6] in order to replace the aging hardware.

BEAM-ASSISTED GIRDER ALIGNMENT (BAGA)

After an inspection of the vertical misalignment data which were taken for all 177 quadrupoles in 2010, it turned out that the misalignments of neighbouring quadrupoles were highly correlated, indicating that the main source of misalignments is girder discontinuities, i.e. girder-to-girder misalignments, since the quadrupoles are grouped onto 49 magnet girders (12×4 girders for 12 TBA arcs and one special girder for the triplet quadrupole of the Femto laser-slicing insertion). The discontinuities between adjacent magnet girders require the use of dipolar correctors in order to centre the orbit at the location of the BPMs which turns out to be the main source of spurious vertical dispersion. The resulting corrector settings showed a close correlation with the measured quadrupole positions because BPMs are beam-based aligned with respect to an adjacent quadrupole magnet. A re-alignment campaign was consequently launched in April 2011 in order to eliminate these misalignments.

The re-alignment could be performed with stored beam and running fast orbit feedback (FOFB) since the girders are remotely controlled [7] and the orbit effects of the proposed girder movements can be dynamically handled by the orbit correction system. This procedure allows a very precise control of the re-alignment process since the corrector variations within the feedback loop directly reflect the girder manipulations.

The movement of the girders is also monitored by the Hydrostatic Leveling System [7] which in most cases confirms the vertical adjustment within a few μm. Furthermore, by fitting individual quadrupole misalignments to the achieved corrector pattern by means of a model based SVD fit, one can estimate the remaining misalignments after re-alignment. The corrector pattern analysis requires an SVD orbit correction scheme or an equivalent technique, utilizing a large number of (preferably all) eigenvalues in order to localize the girder-to-girder misalignments [8].

As a result of the re-alignment in 2011 the vertical RMS kick of all vertical correctors was reduced from ≈128 μrad to ≈54 μrad which corresponds to a reduction by a factor 2.4 with respect to the initial RMS value before the campaign started [9] (see Fig. 3). This re-alignment was an important prerequisite for the reduction of the vertical emittance to values of <1 pm.rad [9].

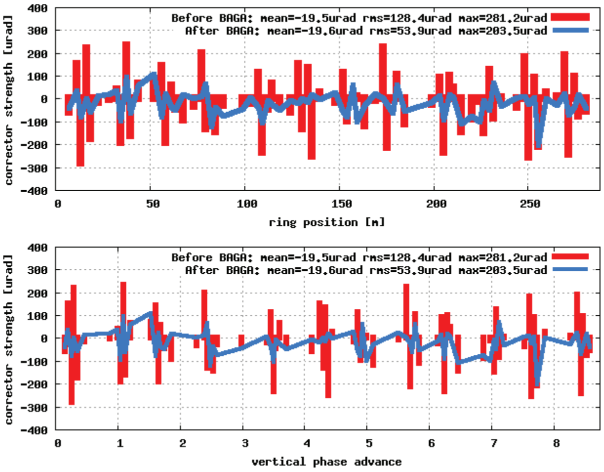

Figure 3: Vertical corrector strength in μrad vs. ring position and vertical betatron phase. The RMS kick reduced from 128.4 μrad before BAGA (red bars) to 53.9 μrad after BAGA (blue solid line).

BEAM-BASED ALIGNMENT (BBA)

Recently the Beam-Based Alignment procedure which is used to determine the offsets (BBA constant) of adjacent quadrupoles and beam position monitors (BPMs) [10] has been integrated with the operation of the FOFB.

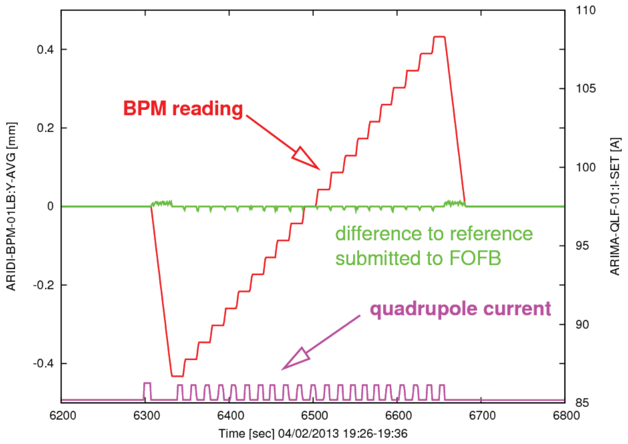

Figure 4: Change of the vertical BPM position (red line) within the FOFB loop during the BBA measurement of one BPM/quadrupole pair.

The RMS difference orbit measurement taken before and after the quadrupole current change has been replaced by a difference kick measurement since the FOFB ideally transforms the orbit variation to a single kick change of the corrector in the vicinity of the quadrupole. The knowledge of this kick is sufficient to determine the BBA constant since the quadrupole variation is known. But in order to increase the precision of the measurement the orbit reference (set point) of the BPM whithin the FOFB loop is altered. Figure 4 depicts the change of the vertical position reading of one BPM (red line) and its difference (green line) to the orbit reference, which is varied from -0.45 to 0.45 mm in 20 steps. The quadrupole current (magenta line) is changed by ≈2% keeping the tune variation small (≈0.015).

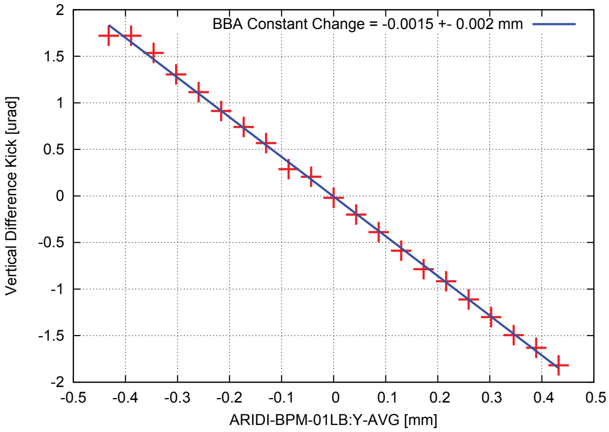

Figure 5: Vertical difference kick (red crosses) as a function of the BPM position reading. A linear fit (blue line) determines the BBA constant change.

The result of the measurement is shown in Fig. 5 where the vertical difference kick (red crosses) is plotted as a function of the BPM position reading. The BBA constant change to an already present BBA correction is found by linear regression (blue line) and taking the fit value (-0.0015±0.002 mm) for a vanishing kick which corresponds to the center of the quadrupole. The already small measurement error of ≈2 um could be further reduced by suppression of the residual kick measurement noise.

SUMMARY

The Beam-Assisted Girder Alignment (BAGA) and Beam-Based Alignment (BBA) of BPM/quadrupole pairs with running Fast Orbit Feedback (FOFB) have shown the potential of the online analysis of perturbations in the corrector space. The measurement conditions are extremely well controlled since the orbit is kept stable by the FOFB. The application of BAGA led to a very small vertical RMS kick of ≈54 μrad. The BBA error is only 2 μm and could be further reduced by refining the measurement procedure.

The application of this technique to linear accelerators running FOFBs is even more promising since the trajectory stability during measurements is much more difficult to maintain than for circular machines which feature closed orbits.

REFERENCES

[1] M. Böge, J. Chrin, “Integrating Control Systems to Beam Dynamics Applications with CORBA”, PAC’03, Portland, May 2003.

[2] M. Böge et al., “Orbit Control at the SLS Storage Ring”, EPAC’02, Paris, June 2002.

[3] M. Böge et al., “Fast Closed Orbit Control in the SLS Storage Ring”, PAC’99, New York, March 1999.

[4] V. Schlott et al., “Performance of the Digital BPM System for the Swiss Light Source”, DIPAC’01, Grenoble, May 2001.

[5] T. Schilcher et al., “Commissioning and Operation of the SLS Fast Orbit Feedback System”, EPAC’04, Lucerne, July 2004.

[6] W. Koprek et al., “Development of new BPM Electronics for the Swiss Light Source”, IBIC’12, Tsukuba, October 2012.

[7] S. Zelenika et al., “The SLS storage ring support and alignment systems”, Nucl. Instr. Meth. A 467 (2001) 99.

[8] M. Böge et al., “The Swiss Light Source - ”A Test Bed” for Damping Ring Optimization”, IPAC’10, Kyoto, May 2010.

[9] M. Aiba et al., “Ultra low Vertical Emittance at SLS through systematic and random Optimization”, Nucl. Instr. Meth. A 694 (2012) 133.

[10] M. Böge et al., “Measurement and Correction of Imperfections in the SLS Storage Ring”, EPAC’02, Paris, June 2002.