THE SWISS LIGHT SOURCE
A "TEST-BED" FOR DAMPING RING OPTIMIZATION

M. Böge, M. Aiba, A. Lüdeke, N. Milas, A. Streun, PSI, Villigen, Switzerland

Abstract

The application of various optics correction techniques at the Swiss Light Source (SLS) allows to reduce the vertical emittance to <3 pm.rad corresponding to an emittance coupling of <0.05%. Beam sizes can be measured with a resolution of ≈0.5 μm allowing to resolve vertical emittances close to the quantum radiation limit of 0.2 pm.rad. The application of beam-based alignment/calibration techniques on magnet girders (remotely controlled), quadrupoles and sextupoles can be used to center the beam in all relevant optical elements at a minimum expense of vertical dipole corrector strength. Furthermore a fast orbit feedback based on a high resolution digital BPM system allows to stabilize the closed orbit up to ≈90 Hz and to perform precise orbit manipulations within this bandwidth. Furthermore the top-up operation mode guarantees very stable conditions for the various beam-based measurements. These conditions make the SLS an excellent "test-bed" for future damping ring optimization.

INTRODUCTION

One of the main aims of 3rd generation synchrotron light sources like the SLS and future damping rings is the minimization of the vertical emittance. This goal is accomplished by the careful correction of betatron coupling and spurious vertical dispersion to very small values. Furthermore light sources need a well defined control of the vertical emittance in order to vary the beam lifetime.

It is unfortunate that even after excellent (≈5 μm RMS) Beam-Based Alignment (BBA) of quadrupoles with respect to adjacent Beam Position Monitors (BPMs) remaining vertical orbit deviations in sextupoles lead to significant betatron coupling and spurious vertical dispersion.

A way to correct for this coupling is the introduction of extra skew quadrupoles at dispersive (η_x>0) and non-dispersive (η_x=0) locations of the lattice in order to control spurious vertical dispersion η_y and betatron coupling. At the SLS 24 non-dispersive and 12 dispersive skew quadrupoles have been installed for this purpose. All 120 sextupoles in the SLS are equipped with extra windings where only 72 are dedicated as dipole correctors for orbit correction. The remaining 48 can be connected as desired to be for example skew quadrupoles or correction sextupoles. Since 12 of them have been devoted to nonlinear optics correction [1] 36 are left to be used as skew quadrupoles which in principle also opens the possibility to perform a BBA on 36 sextupoles by using those skew quadrupoles [2][3].

BETATRON COUPLING AND DISPERSION CORRECTION

An SVD based betatron coupling correction scheme based on the measured coupled BPM/Corrector response matrix meanwhile utilizing all 24 non-dispersive skew quadrupoles is regularly employed to minimize the betatron coupling [4]. After the application of 2-3 iterations of betatron coupling corrections the RMS of the coupling terms of the coupled BPM/Corrector response matrix is typically reduced by a factor ≈2-2.5 which corresponds to a factor ≈4-6 in the corresponding vertical emittance contribution due to betatron coupling. In addition empirical manipulation of the three first order modes of the skew quadrupole Hamiltonian using the ratio of beam lifetime to beam height as a tuning parameter leads to a further reduction of the betatron coupling [1].

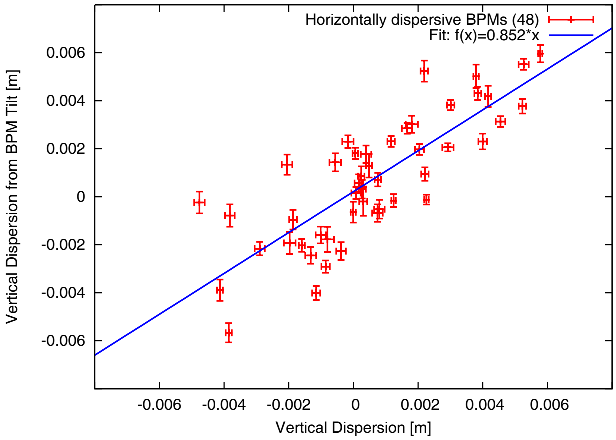

Figure 1: Correlation of the "fake" vertical dispersion introduced by tilts of 48 BPMs with finite η_x and the measured spurious vertical dispersion.

The correction values for the twelve dispersive (η_x≈0.3 m) skew quadrupoles are determined by applying the SVD "inverted" (no weighting factor cut) model-based [5][6] 73x12 sensitivity matrix $\partial\eta_{yi}/\partial k_{sj}$, where η_{yi} denotes η_y at the location of the BPM i and k_{sj} is the strength of the skew quadrupole j, to the measured spurious vertical dispersion η_y. Assuming the absence of any BPM tilt η_y can be corrected to ≈2.0 mm.

Recent direct measurements of the BPM tilts show a clear correlation with η_y at BPMs with finite η_x≈0.2 m indicating that the measurement of η_y is significantly (to ≈80%) corrupted by BPM rotations as it can be seen in

Fig. 1 correlating the "fake" vertical dispersion introduced by tilts of 48 dispersive BPMs and the measured spurious vertical dispersion.

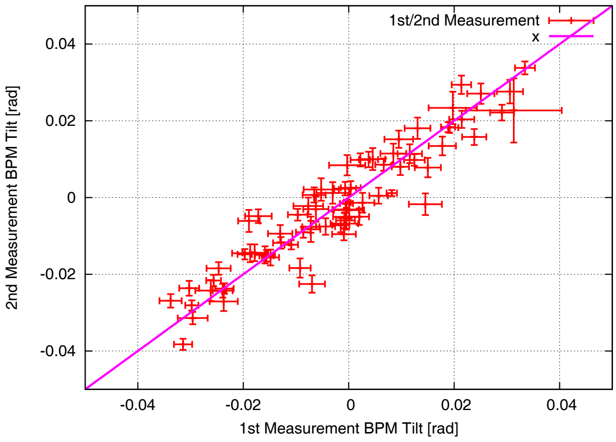

Figure 2: Two successive measurements of the rotational errors of 73 BPMs which reveal a surprisingly large RMS tilt of ≈17 mrad.

These tilt measurements have been performed by utilizing the fast orbit feedback (FOFB) system [7]. By changing the vertical orbit reference of individual BPMs by ±150 μm with running FOFB, correctors in the vicinity of the BPM are excited within the FOFB loop in order to accomplish the requested vertical orbit change. The BPM tilt is then determined by recording the correlated change of horizontal and vertical dipole corrector values and using the corresponding tilt prediction by the machine model simulating the reference orbit change in presence of a non-vanishing BPM tilt. Fig. 2 depicts the result of two successive measurements which reveal a surprisingly large RMS tilt of ≈17 mrad which is two orders of magnitude larger than the tilt error (≈200 μrad) of the involved dipole correctors. The magnitude of the RMS value cannot be explained by mechanical misalignment of the vacuum chamber or the button arrangement and must therefore be of electronical origin.

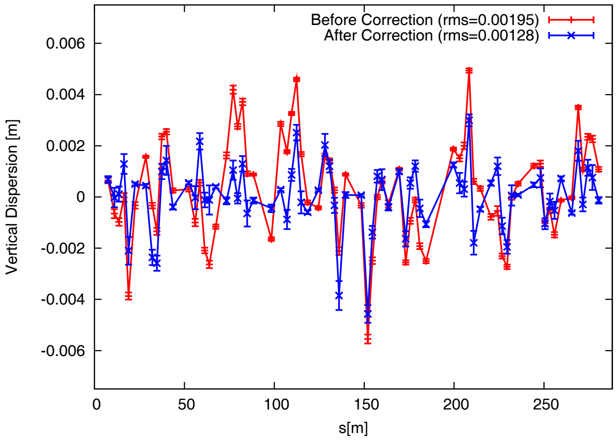

Figure 3: The setting for twelve dispersive (η_x≈0.3 m) skew quadrupoles is determined by an SVD fit to the measured spurious vertical dispersion η_y without any weighting factor cut. Taking into account the measured BPM tilts, shown in Fig. 2, reduces the already corrected η_y ≈2.0 mm (red points +) to ≈1.3 mm RMS (blue points ×).

As shown in Fig. 3 the already corrected η_y (red points +) of ≈2.0 mm RMS can be further reduced to ≈1.3 mm RMS (blue points ×) by taking the measured BPM tilts into account. The maximum applied $|k_s|$ of ≈0.002 m^{-1} stays well below the maximum of 0.03 m^{-1} at 7 A (the twelve applied weigthing factors are in the range from 0.17 down to 0.03).

BEAM-BASED GIRDER RE-ALIGNMENT

In order to approach the ultimate limit, which is given by the present η_y measurement resolution of ≈0.3 mm, sources of η_y need to be eliminated. After analysing the vertical corrector pattern (red impulses) shown in Fig. 4 Girder-to-girder misalignments in the arc centers at the location of the central dipoles BX_i, which are in the range of 50-100 μm (black circles) could be identified to be the major source of η_y. A re-alignment campaign has been initiated to eliminate these misalignments which are well within the initial specification of the girder joint play (100 μm RMS). As a side effect this re-alignment will reduce the RMS vertical dipole corrector strength from ≈140 μrad to <100 μrad. The described technique requires an SVD orbit correction scheme utilizing a large number of (preferably all) eigenvalues in order to localize the girder-to-girder distortions. The calculated corrections do not necessarily have to be applied to the real machine.

Another possibility to reduce η_y has been considered already during the SLS design stage. It uses the entire magnet assembly on the remotely controlled girders as "supercorrectors" to correct for orbit deviations [8]. The girders simply become the actuators in an SVD based orbit correction scheme. Simulations have shown that all static vertical closed orbit corrections can be covered by girder re-alignment; horizontally, a proper selection of girders to be re-positioned allows to reduce the corrector magnet strengths by a factor 4. Since such a mechanical re-alignment is potentially eliminating orbit distortions right at the source a significant reduction of η_y can be expected.

EMITTANCE MEASUREMENT

To enable an emittance measurement at a synchrotron light source an image formation method is typically used for the determination of the beam size. The emittance determination thus relies on a beam size measurement and knowledge, through other means, of the beta and dispersion values at the observation point. A determination of an RMS beam size of <10 μm requires a large instrumental and theoretical effort. At the SLS "the π-polarization method" has

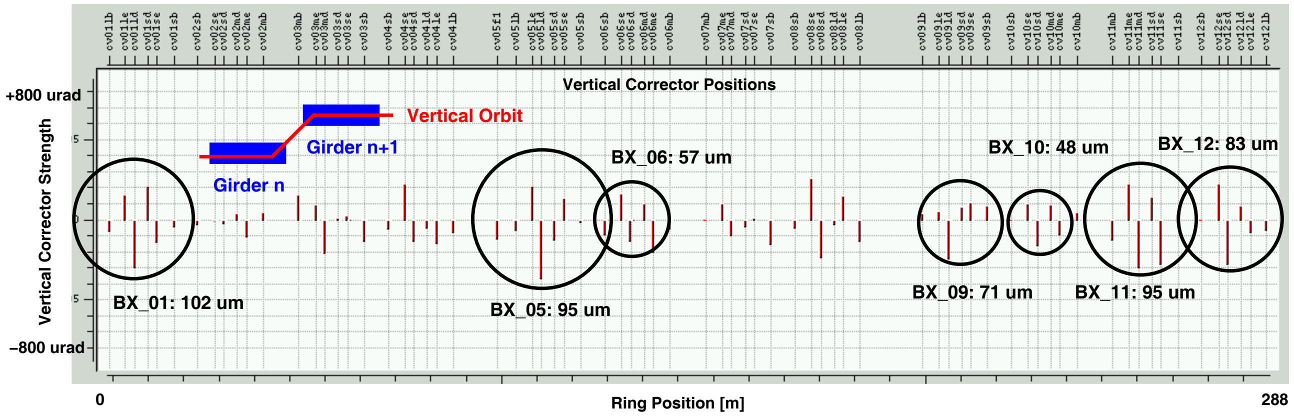

Figure 4: Girder-to-girder misalignments in the arc centers at the location of the central dipoles BX_i bridging adjacent girders, which are in the range of 50-100 μm (black circles) could be been identified to be the major source of η_y by analysing the vertical corrector pattern (red impulses). The cartoon depicts the step in the vertical orbit which is introduced by the relative misalignment of two girders n and n+1.

been chosen in order to reach this ambitioned goal [9][10]. In this setup images are formed from vertically polarized vis-UV synchrotron radiation. It has been demonstrated at the SLS that this method is capable of determining beam sizes σ_e to well below 10 μm with a resolution of ≈0.5 μm. Fig. 5 depicts a top view of the diagnostics beam-line located at the central dipole ARIMA-BX-09 in sector 9 of the SLS.

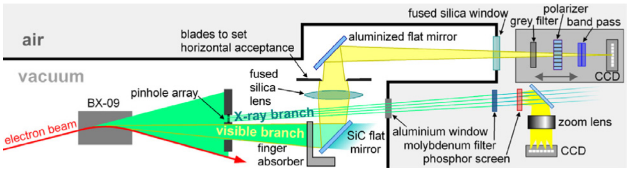

Figure 5: Layout of the high resolution emittance measurement beam-line operated at the central dipole ARIMA-BX-09, showing the X-ray branch with pinhole array and the vis-UV branch [9][10].

CONCLUSION

Utilizing this precise measurement technique very small vertical emittances of <3 pm.rad have been resolved after application of the various optics correction techniques described.

It has been shown that there is the potential to reduce these values even further which is mainly achieved by the application of refined dispersion correction schemes and careful mechanical re-alignment guided by orbit measurements.

Recently the Paul Scherrer Institute joint a collaboration with CERN on possible damping ring studies at the SLS. The "Workshop on Low Emittance Rings (LER2010)" [11] held at CERN and organized by the joint ILC/CLIC working group very successfully brought together experts working on low emittance lepton rings (including damping rings, test facilities for linear colliders, B-factories and electron storage rings) in order to discuss common beam dynamics and technical issues. The workshop documented that especially damping ring designers can largely profit from the "Low Emittance Design and Tuning" knowledge within the light source community.

The goal of this collaboration is to develop the Swiss Light Source further in terms of correction capabilities and diagnostics in order to make this machine an even better "test-bed" for future damping ring optimizations.

REFERENCES

[1] M. Böge et al., "Correction of Imperfections in the SLS Storage Ring Lattice", PAC'09, Vancouver, May 2009.

[2] M. Kikuchi et al., "Beam-Based Alignment of Sextupoles with the Modulation Method", PAC'95, Dallas, May 1995.

[3] M. Ross et al., "Beam Based Alignment at the KEK Accelerator Test Facility", EPAC'02, Paris, June 2002.

[4] M. Böge et al., "Ultra-Low Vertical Emittance at the SLS", PAC'09, Vancouver, May 2009.

[5] J. Bengtsson, "TRACY-2 User's Manual", Internal SLS document, PSI, Villigen, 1997.

[6] M. Böge, "Update on TRACY-2 Documentation", SLS-TME-TA-1999-0002, PSI, Villigen, 1999.

[7] T. Schilcher et al., "Commissioning and Operation of the SLS Fast Orbit Feedback System", EPAC'04, Lucerne, July 2004.

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

[9] Å. Andersson et al., "Determination of a Small Vertical Electron beam Profile and Emittance at the Swiss Light Source", Nucl. Instr. Meth. A 591 (2008) 437.

[10] Å. Andersson et al., "Electron Beam Profile Measurements with Visible and X-Ray Synchrotron Radiation at the Swiss Light Source", EPAC'06, Edinburgh, June 2006.

[11] Homepage LER2010, http://ler2010.web.cern.ch/.