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ORBIT CORRECTION AND STABILITY STUDIES FOR ULTRA-LOW EMITTANCE STORAGE RINGS

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Abstract

Ultra-low emittance storage rings exhibit extremely strong focusing and sextupolar chromaticity corrections. The therefore mandatory excellent centering of the closed orbit in the small aperture magnets is a challenging task and necessitates a proper beam diagnostics and correction layout. Correction and stability studies for a possible ultra-low emittance upgrade of the Swiss Light Source [1] are presented.

LAYOUT FOR BEAM POSITION MONITORS AND DIPOLE CORRECTORS

In order to perform a proper optics and orbit correction of ultra-low emittance rings it is necessary to provide a proper sampling of the optical functions. Especially the horizontal beta function and the horizontal dispersion, which are strongly suppressed in the center of the bending magnets in order to achieve small horizontal emittance [2], need to be corrected close to their design values in order to achieve ultimate performance. The necessary information in the center of the bends can be provided by means of photon beam position monitors (photon BPMs) [3]. It does not necessarily need correction capability at the same location since orbit response matrix (ORM) based optics correction methods [4] and the correction of dispersion orbits by means of the RF frequency only need the orbit information at these locations. In this context it is important to note that the detection of dispersion related orbit deviations is strongly improved by providing orbit measurements at large and small horizontal dispersion values.

The correction of the non-dispersive closed orbit can be provided by correctors adjacent to the bending magnets. Furthermore horizontal dipole correctors would be inefficient due to the very small horizontal beta function (see Fig. 1 on the next page). Otherwise it is highly desirable to have pairs of horizontal and vertical dipole correctors adjacent to electron BPMs (RF BPMs) in order to allow for transparent localized corrections especially in the vicinity of insertion devices in the case of an ultra-low emittance light source. For a comprehensive review of orbit control techniques refer to [5].

For one of the presently favored layouts (Version AD05F) of the upgrade of the Swiss Light Source (SLS-2) [1] 192 RF BPMs and the same number of adjacent horizontal/vertical correctors have been chosen in order to provide the necessary orbit correction capability. For the measurement of the beam positions in the centers of the bending magnets five photon BPMs have been added in each of the twelve arcs which adds another 60 photon BPMs to the system. Figure 1 on the next page depicts one arc section of SLS-2 (Version AD05F) together with the optical functions and the additional photon BPMs (#1-#5). Figure 2 summarizes the photon and RF BPM layout with 20+64=84 BPMs for one 3rd of the ring corresponding to a horizontal and vertical phase advance of 13.14 and 3.585 respectively. The BPMs are shown as "+" with the value of the corresponding horizontal (blue), vertical (red) beta function and the horizontal dispersion (green).

SCHEME FOR ORBIT CORRECTION

In the SLS-2 case the orbit correction is carried out utilizing a Singular Value Decomposition (SVD) [6] based orbit correction algorithm, which "inverts" the (192+60)x192 non-square ORMs treating the horizontal and vertical plane independently and using all 192 eigenvalues, which becomes feasible due to a "good-natured" SVD eigenvalue spectrum, a proper Beam-Based Alignment (BBA) [7] of quadrupoles and adjacent BPMs (half the element-to-element error corresponding to 4μm assumed in simulation) and a low noise BPM [8] ($\approx$50 nm resolution corresponding to 19-bit resolution assuming $\pm$25 mm maximum orbit excursions) and correction system ($\approx$1 nrad resolution corresponding to 20-bit for maximum corrector strength of $\pm$1 mrad) [9].

LAYOUT OF MAGNET SUPPORTS

Common magnet supports (girders) are very important in order to reduce the element to element alignment error in low emittance storage rings like SLS [10, 11]. They allow to reach a small relative misalignment of adjacent magnets on a girder (8 μm assumed in the simulation for SLS-2) which are the main source of orbit distortions and coupling. A single magnet structure containing different magnetic elements [12] serves the same purpose but removes the possibility of aligning magnets within the structure. For SLS-2 the choice of the magnet structure has not yet been made. But this does not matter for the simulation since in both cases the magnet structures are realized as "correlated" misalignments. For the simulation 12 girders of $\approx$18 m length have been chosen which cover the 12 arcs. 25 μm of absolute and 10 μm of relative misalignment from one girder to the next have been allowed. These small errors have been chosen since the simulation does not contain first turn steering ("beam threading") in order to get a closed orbit within the aperture limitations for large errors. Furthermore it is assumed that the ring has been re-aligned during commissioning time based on beam and mechanical survey data [13–15].

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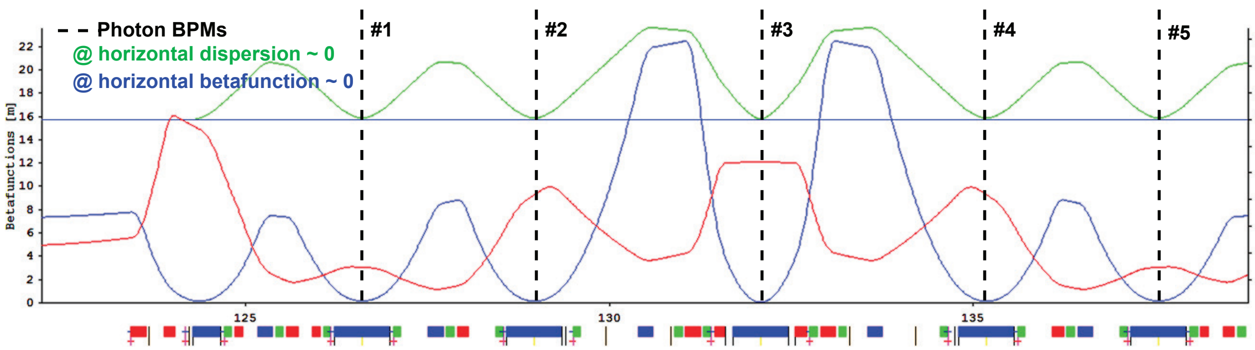

Figure 1: One arc section of the SLS-2 lattice (Version AD05F) with a schematic view of the magnets at the bottom (dipole magnets in blue) and the optical functions. The horizontal beta function (blue) and the horizontal dispersion (green) vanishes in the center of the bending magnets in order to provide small horizontal emittance. Five additional photon BPMs (#1-#5) have been added in the center of the main bends for improved orbit sampling.

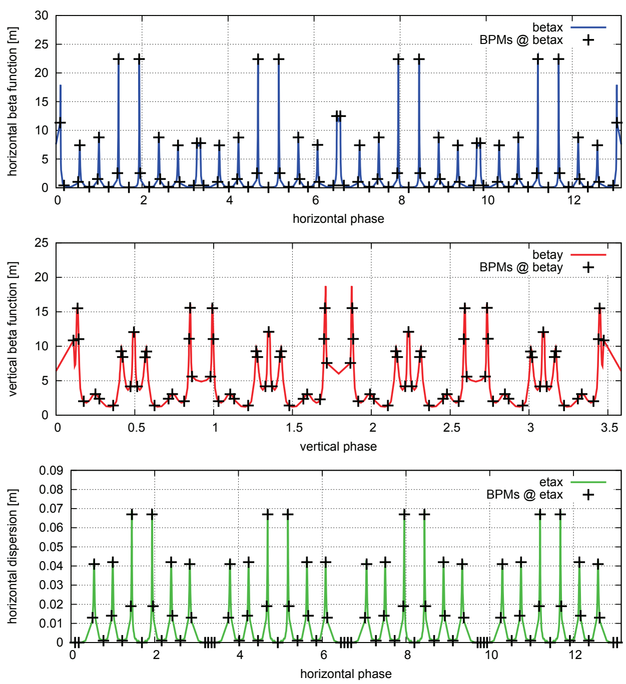

Figure 2: Photon and RF BPM layout with 20 photon and 64 RF BPMs for one 3rd of SLS-2. BPMs are visualized as "+" with the values of the corresponding beta functions and horizontal dispersion, where the total phase advance of SLS-2 (Version AD05F) is 39.417 and 10.755.

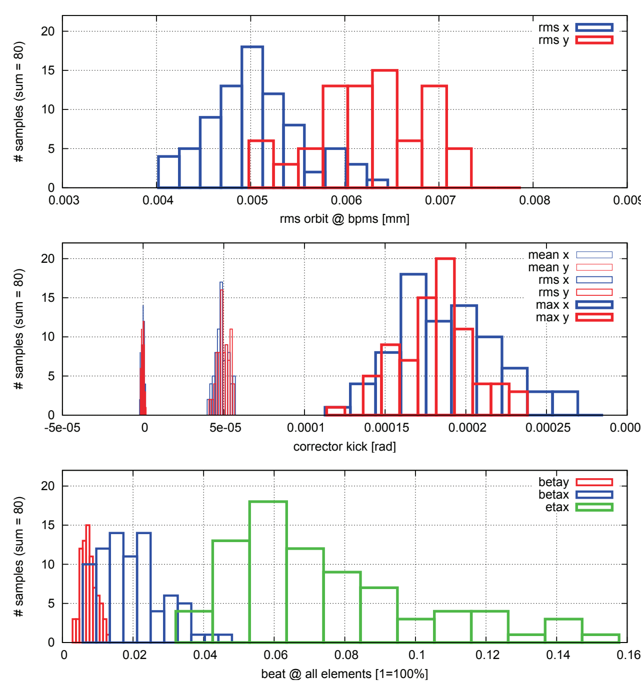

Figure 3: Graph 1: Residual horizontal (mean rms 5 μm) and vertical (mean rms ≈6 μm) rms orbit taken at the locations of the BPMs for 80 error distributions (Note that the rms is non-zero since the number of BPMs exceeds the number of correctors), Graph 2: Necessary rms corrector strength (mean rms ≈50 μrad in both planes, mean maximum ≈175 μrad), Graph 3: Resulting beta (mean ≈1-2 % in both planes) and dispersion beat (mean ≈7 %).

SIMULATIONS

Simulations [16, 17] for the AD05F lattice have been carried out for 80 different Gaussian BPM and magnet error distributions with a two sigma cut. After convergence of the SVD based orbit correction the resulting residual orbit deviations at the location of the BPMs are non-zero ≈5-6 μm (see Fig. 3, Graph 1) in the both planes since the 60 photon BPMs in the dipole centers do not have adjacent orbit correctors. The corrector strength needed has a mean rms of ≈50 μrad with mean maximum values of ≈175 μrad (see Fig. 3, Graph 2). The resulting mean beta beats are smaller than ≈2 % in both planes. The horizontal dispersion beat is large ≈7 %. As expected the main contributions to this beat are originating from deviations from the very low design dispersion values in the dipoles centers (see Fig. 3, Graph 3).

An important ingredient for the desired orbit tuning of the lattice are localized orbit deviations generated by interleaved (1-2-3,2-3-4,...) closed orbit bumps consisting of 3-4

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correctors. Results are shown for bumps with 3 successive correctors (3-bumps). Since they are interleaved a total of 192 bumps can be constructed. Graph 1 in Fig. 4 shows histograms of the weakest corrector strength in a 3-bump for a reading of 50 nm (assumed BPM resolution) at the BPM in the center of the 3-bump. The minimum horizontal/vertical kick needed is found to be ≈3/5 nrad. This is well above the earlier assumed corrector resolution of 1 nrad corresponding to a 20-bit resolution for a maximum corrector strength of 1 mrad. Graph 2 in Fig. 4 depicts histograms of the strongest corrector in a 3-bump for a central BPM reading of 100 μm which is considered to be a typically needed orbit steering. The strongest correctors stay below 400 μrad for this bump amplitude and therefore a factor of two below the assumed maximum corrector strength of 1 mrad.

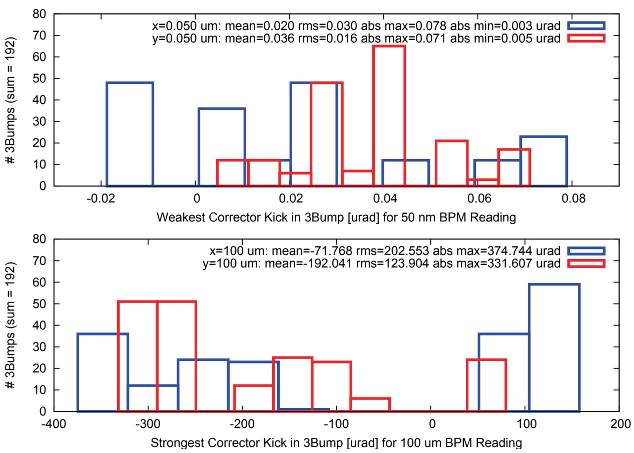

Figure 4: Graph 1: Histograms of the weakest horizontal (min ≈3 nrad) and vertical correctors (min ≈5 nrad) in 192 interleaved 3-bumps for a 50 nm BPM reading (BPM resolution) in the 3-bump center, Graph 2: Histograms of the strongest horizontal (max ≈375 μrad) and vertical correctors (max ≈330 μrad) for a 100 μm BPM reading (BPM resolution) in the 3-bump center.

SUMMARY

Strategies for achieving a proper beam diagnostics and correction layout for ultra-low emittance rings have been presented taking the planned upgrade (SLS-2) of the Swiss Light Source as an example. It has been shown that the presented layout can provide the necessary optics and orbit control needed in such a ultra-low emittance light source.

Furthermore the necessary BPM and corrector resolution at given maximum strength which is needed for the demandingly high orbit stability requirements have been estimated for one of the SLS-2 lattices (Version AD05F). Since the SLS-2 project is still at a very early stage the presented simulation results should be considered to be preliminary.

REFERENCES

[1] A. Streun et al., TUPJE047, "Design Studies for an Upgrade of the SLS Storage Ring" , *These Proceedings*, IPAC'15, Richmond, USA, May 2015.

[2] A. Streun and A. Wrulich, Nucl. Instrum. Methods Phys. Res. A 770 (2015) 98–112.

[3] K. Holldack, J. Feikes and W.B. Peatman, "Review of Emittance and Stability Monitoring using Synchrotron Radiation Monitors", DIPAC'01, Grenoble, France, May 2001.

[4] J. Safranek, "Experimental Determination of Storage Ring Optics using Orbit Response Measurements", Nucl. Instrum. Methods Phys. Res. A388 (1997) 27–36.

[5] C.J. Bocchetta, "Review of Orbit Control", EPAC'98, Stockholm, Sweden, June 1998.

[6] W.H. Press et al., "Numerical Recipes: the Art of Scientific Computing", Cambridge University Press, New York, 1986.

[7] P. Röjsel, "A Beam Position Measurement System using Quadrupole Magnets Magnetic Centra as the Position Reference", Nucl. Instrum. Methods Phys. Res. A343 (1994) 374–382.

[8] W. Koprek et al., "Development of new BPM Electronics for the Swiss Light Source", IBIC'12, Tsukuba, Japan, October 2012.

[9] F. Jenni et al., "A novel Control Concept for Highest Precision Accelerator Power Supplies", EPE-PEMC 2004, Riga, Latvia, September 2004.

[10] S. Zelenika et al., "The SLS Storage Ring Support and Alignment Systems", Nucl. Instrum. Methods Phys. Res A467-468 (2001) 99–102.

[11] M. Böge, "Achieving Sub-micron Stability in Light Sources", EPAC'04, Lucerne, Switzerland, July 2004.

[12] H. Tarawneh et al., "MAX-IV Lattice, Dynamic Properties and Magnet System", Nucl. Instrum. and Methods Phys. Res. A508 (2003) 480–486.

[13] M. Aiba et al., "Ultra low Vertical Emittance at SLS through Systematic and Random Optimization", Nucl. Instrum. and Methods Phys. Res. A694 (2012) 133.

[14] M. Böge et al., "The Swiss Light Source - "A Test Bed" for Damping Ring Optimization", IPAC'10, Kyoto, Japan, May 2010.

[15] M. Böge et al., "Determination of Sources of Orbital Distortions in Corrector Space", IPAC'13, Shanghai, China, May 2013.

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

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