SLS VERTICAL EMITTANCE TUNING

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Abstract

To establish ultra-small vertical emittances (<1 pm.rad at 2.86 GeV) is one important aim of future linear collider damping ring optimization studies (In January 2011 the EU-project TIARA (Test Infrastructure and Accelerator Research Area)[1] started with contributions from the SLS as part of the SVET (SLS Vertical Emittance Tuning) work package WP6 [1].) at the SLS. By utilizing various correction techniques the SLS is already close to this goal with emittances of < 2pm.rad at 2.4 GeV under the constraint of maintaining user operation conditions. One of the limiting contributions is the remaining spurious vertical dispersion η_y of 1.4 mm RMS which can be reduced by careful re-alignment and the application of dispersion-free steering techniques. The latter require orbit manipulations which are only partially compatible with the user operation mode. A first application of dispersion-free steering techniques demonstrates that η_y can be reduced to <1 mm at the expense of large orbit excursions which require a simultaneous betatron-coupling correction by means of skew quadrupoles in order to benefit in terms of a further reduction of vertical emittance. Therefore possible girder and magnet misalignments are analyzed which allows one to localize the sources of η_y and to eliminate them by re-alignment. A re-alignment campaign based on vertical survey data has been initiated. Following this path the goal to achieve emittances close to 1 pm.rad is within reach.

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 Beam Position Monitors (BPMs) with respect to adjacent quadrupoles [2] remaining vertical orbit deviations in sextupoles, due to the presence of mechanical misalignments, leads 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 [3] 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 [4].

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GIRDER RE-ALIGNMENT WITH BEAM

In order to approach the ultimate limit, which is given by the present η_y measurement resolution of ≈0.1 mm, sources of η_y need to be eliminated. After analysing the vertical corrector pattern, girder-to-girder misalignments in the arc centers at the location of the central dipoles BX_i were identified to be the major source of η_y. As a result a re-alignment campaign has been initiated to eliminate these misalignments. As a side effect this re-alignment reduces the RMS vertical dipole corrector strength from ≈140 μrad to <100 μrad. The described pattern analysis requires an SVD orbit correction scheme utilizing a large number of (preferably all) eigenvalues in order to localize the girder-to-girder distortions [5, 6].

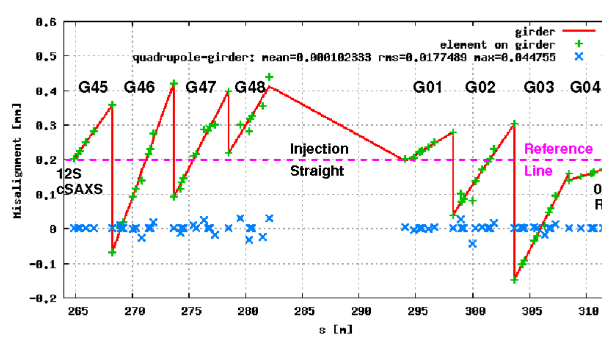

Figure 1: Quadrupole misalignments (green + symbols) in the sectors left and right of the injection straight. The red line is the corresponding girder fit for eight girders (**G45-48**, **G01-04**). The deviation of the individual quadrupole errors from the fit (blue x symbols) features an RMS value of only ≈18 μm which is ≈10 times smaller than the fitted RMS girder misalignments.

After an inspection of the vertical misalignment data which were taken for all quadrupoles in 2010, it turned out that the corrector settings are closely correlated to the measured quadrupole positions. Furthermore the misalignments of the 177 quadrupoles are highly correlated since they are grouped on 49 girders which are the main source of the misalignments. As an example Fig. 1 depicts the quadrupole misalignments (green + symbols) in the sectors left and right of the injection straight. The red line is the corresponding girder fit for eight girders (**G45-48**, **G01-04**). The deviation of the individual quadrupole errors from the fit (blue x symbols) features an RMS value of only $\approx$18 μm which is $\approx$10 times smaller than the fitted RMS girder misalignments. Figure 2 summarizes the necessary

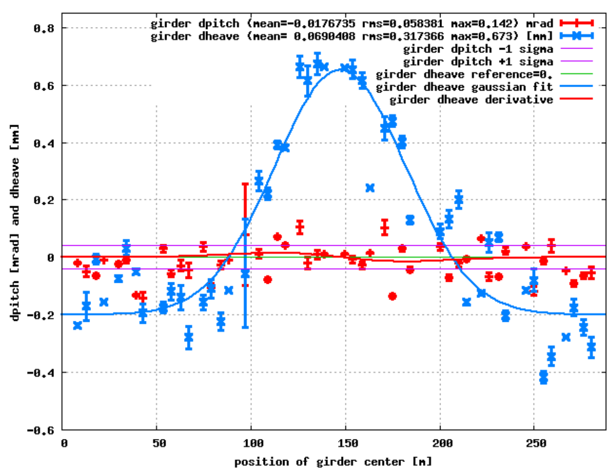

Figure 2: Pitch (red + symbols) and heave changes (blue x symbols) for all girders based on the quadrupole misalignment survey data taken in 2010.

pitch (vertical angle) changes (red + symbols) and heave (vertical position) changes (blue x symbols) for all girders. Since the suggested heave corrections exceed +0.6 mm a reference line (blue line) has been defined by a gaussian fit to the corrections. It should be noted that the re-alignment of the girders to this smooth non-zero reference line does not effect the machine performance due to its long spatial wavelength.

In April 2011 the re-alignment campaign was launched based on the 2010 survey data. Since then 9 out of 12 sectors were successfully re-aligned. The re-alignment was merely done with stored beam and running fast orbit feedback [7] since the girders are remotely controlled [8] 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. As an example the vertical corrector kicks in sector 1 are shown in Fig. 3 before (red bars) and after re-alignment (green bars). It can be seen that the RMS kick reduces from 147 to 55 μrad. Since the $\approx$20 m long arc vacuum chambers do not follow this movement completely a successive beam-based calibration of 6 quadrupole/BPM pairs leads to a further reduction to 38 μrad (magenta bars).

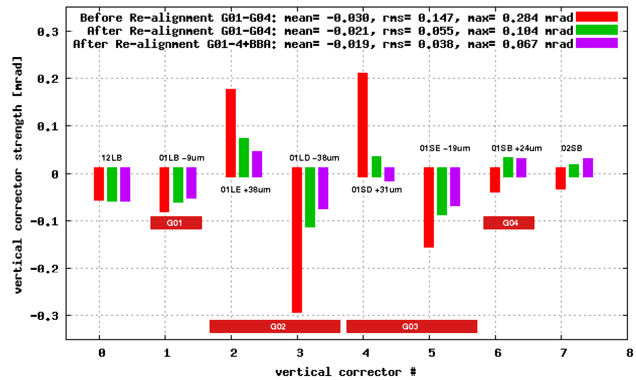

Figure 3: Vertical corrector kicks in sector 1 before (red bars), after the re-alignment (green bars) and after successive beam-based calibration of 6 quadrupole/BPM pairs (magenta bars). An RMS kick reduction by a factor of $\approx$4 could be achieved.

By fitting individual quadrupole misalignments to the achieved corrector pattern by means of a model based SVD fit [9, 10] one can estimate the remaining misalignments after re-alignment (See Fig. 4). One has to have in mind that heave changes are not well reproduced by the SVD fit since they have a rather small influence on the corrector pattern. It can be seen that the girders are nearly perfectly aligned after the correction (black circle). As a result of the recent

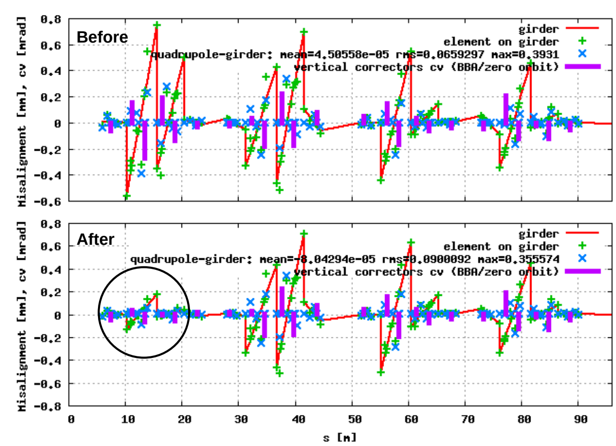

Figure 4: Model based SVD fit of vertical quadrupole misalignments with successive girder fit to the corrector pattern before and after the re-alignment.

re-alignment of sectors 3,5 and 10 at the beginning of August the vertical RMS kick of all vertical correctors was reduced to $\approx$81 μrad which corresponds to a reduction by a factor 1.7 with respect to the initial RMS value before the campaign started. The remaining sectors 4,9 and 11 could not be re-aligned yet since persisting motor readback failures do not allow one to move most of the girders in those sectors. It is expected that the vertical RMS kick will go down to ≈60 μrad once the problem has been solved.

Unfortunately there was not much time to investigate the effect on spurious vertical dispersion and betatron coupling. Nevertheless dispersion values close to ≈1 mm could be achieved recently utilizing the 12 dispersive skew quadrupole corrrectors which goes beyond the previous “hard limit” of 1.3 mm [5].

DISPERSION-FREE STEERING

In order to reduce the spurious vertical dispersion further one can also think of applying dispersion-free steering techniques which involve manipulations of the vertical orbit. At the SLS these manipulations must be compatible with the steerings for insertion devices if they are supposed to be applied under user operation conditions. Two different methods have been tried before the re-alignment ignoring the mentioned constraint. The first method utilizes the 73 individual vertical correctors in order to correct for vertical dispersion. To this end the dispersion response of all correctors is determined within the machine model. The corresponding response matrix is then inverted using SVD with a properly chosen eigenvalue cut-off in order to keep the orbit variations small [11]. The second method uses 3-bumps consisting of 3 successive correctors instead [12]. In principle both methods will converge to the same optimum when using a large number of eigenvalues. But the latter method has the advantage that the superimposed bumps do not cause a betatron oscillation around the ring and thus is more promising in terms of the compatibility with the user operation mode. Both methods have the inherent problem that the orbit excursions potentially enhance betatron coupling due to orbit excursions in sextupoles but it has been shown in the case of the SPS that it is possible to reduce the betatron coupling simultaneously [12]. Ignoring the compensation of betatron coupling both methods have been tried leading to dispersion values of ≈1 mm in both cases. Figure 5 depicts the orbit excursions with an RMS of 310 μm after the reduction of the vertical dispersion from 1.4 mm to 1.1 mm using the individual corrector method. An eigenvalue cut-off had to be applied in order to limit the corrector strength and orbit variation.

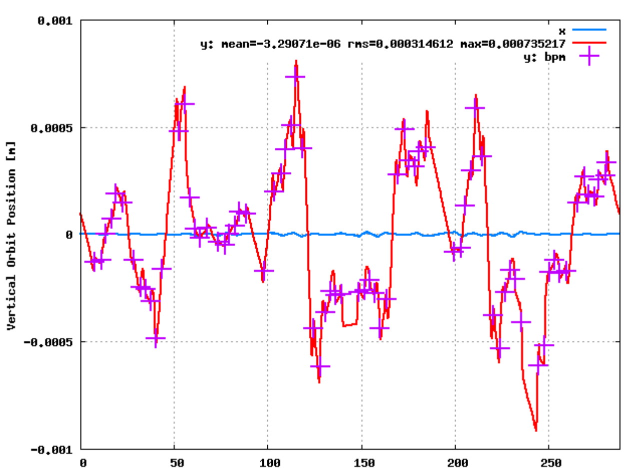

Figure 5: Orbit excursions with an RMS of 310 μm after reduction of the vertical dispersion to 1.1 mm using the individual corrector method.

SUMMARY

A nearly complete vertical re-alignment of the SLS has been carried out within a few months. The vertical RMS corrector kick could be reduced from 140 to ≈81 μrad. It is expected to achieve ≈60 μrad after completion of the re-alignment. The procedure is based on the vertical quadrupole survey data taken in 2010 and involves the remotely controlled movement of 48 girders with circulating beam with operating fast orbit feedback. The resulting corrector changes have been used to estimate the remaining misalignment of the girders. Please note that there is a significant difference to the beam-based girder alignment initially proposed where the girders are moved based on orbit measurements [8]. Two different dispersion free steering techniques have been successfully applied to minimize spurious vertical dispersion. Both methods involve vertical orbit deviations which are potentially incompatible with the user operation mode at SLS. Nevertheless both methods allow one to correct vertical dispersion to values <1 mm. It is planned to utilize these techniques after the re-alignment again in order to minimize dispersion.

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