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Beam Stability and Dynamic Alignment at SLS

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BEAM STABILITY AND DYNAMIC ALIGNMENT AT SLS

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Abstract

Long and short term stability of the electron beam in the storage ring of the Swiss Light Source (SLS) is achieved by dynamic alignment systems and by fast closed orbit feedback.

Quadrupoles, sextupoles and BPMs are rigidly mounted on girders, while the bending magnets are bridging adjacent girders. Positioning of the girders is performed by mover systems based on excenters and encoders. The girder positions are monitored by a hydrostatic leveling system and a digital encoder based horizontal positioning system. Another encoder based system for controlling the BPM positions relative to adjacent quadrupoles is calibrated by beam based alignment.

Residual noise of the electron beam has been estimated by investigation of seismic spectra, girder eigenfrequencies, beam amplification factors and capabilities of the fast orbit feedback system.

We will describe the systems, summarize the status by September 2001 and show first results. Technical and mathematical details of dynamic alignment are described in references [2] and [3]. The orbit feedback is described in detail in reference [6].

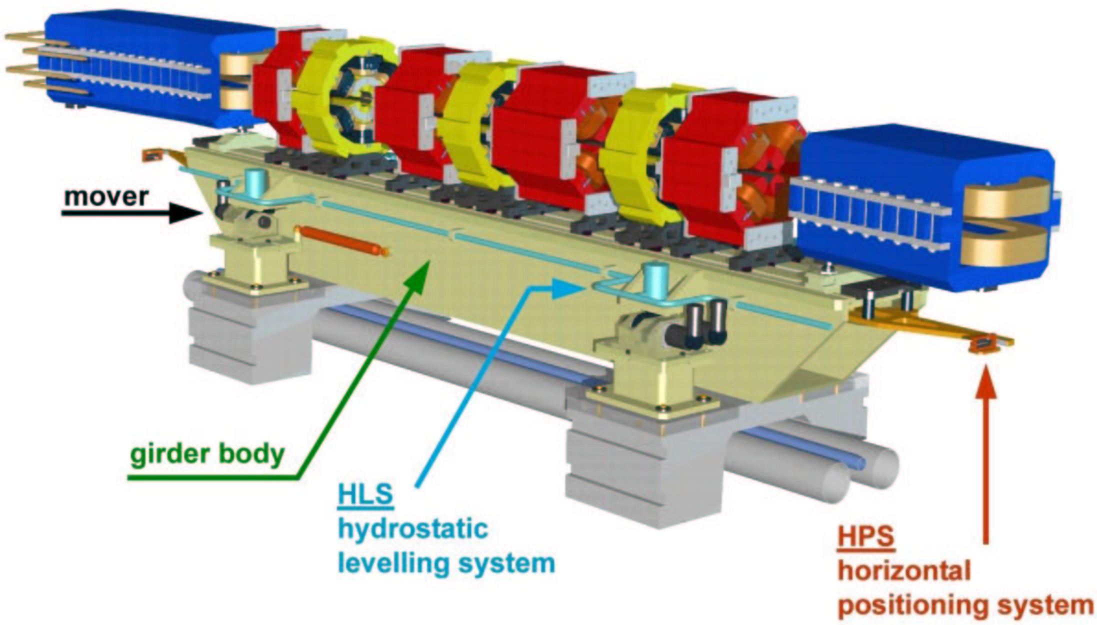

Figure 1: SLS girder assembly

1 DYNAMIC ALIGNMENT

The 174 quadrupoles and 120 sextupoles (with integrated correctors) of the SLS storage ring [1] are fixed rigidly to 48 girders by means of alignment rails with tolerances of less than ±15 µm. The bending magnets, supported by 3 point ball bearings overlap adjacent girders as shown in figure 1. Four girders and the three bending magnets between form one of the 12 triple bend achromats of the SLS lattice.

A girder has six degrees of freedom to move: We define a local coordinate system of the girder with its origin at the beam and above the girder's center. The x-axis points to the ring outside (to the back in figure 1), the y-axis points up and the z-axis points in the direction of the beam (to the right in figure 1).

The translations into x, y and z direction are abbreviated by symbols **u,v,w** and called **sway**, **heave** and **surge**. The counterclockwise rotations around x, y and z axis are abbreviated by symbols χ, η, σ and called **pitch**, **yaw** and **roll**.

Girder Movers and Encoders

Each girder is supported by 5 girder movers (GM) using eccentric cam shaft drives for moving in the five degrees of freedom sway, heave, pitch, yaw and roll, which have a first order effect on the beam. Digital encoders on the girder movers (GME) read back the angles of the excenters for recalculation and check of the girder position. Each girder movers consists of an excenter in z-direction on ground and a contact surface at the girder. Four of the contact surfaces are slanted by 45°, the fifth is horizontal. With an excenter radius of 5 mm the ranges of movement amount to several mm, resp. mrad if only one parameter is varied. The *common* working region for independent variation of all five parameters allows following ranges for the two types of short (3.7 m) and long (4.5 m) girders:

Translation [mm]	short	long	Rotation [mrad]	short	long
Sway u	1.41	1.41	Pitch χ	1.41	1.01
Heave v	1.41	1.41	Yaw η	1.41	1.01
Surge w	-	-	Roll σ	1.49	1.49

The vacuum chamber extends over one sector, i.e. over four girders and three bending magnets without any bellow [4]. Thus moving the girders will bend the vacuum chamber. In order to protect the vacuum chamber from too large stresses, safety switches limit the relative movements between adjacent girders.

Hydrostatic Levelling System

A hydrostatic leveling system (HLS) gives an absolute vertical reference. Four measurement pots per girder allow to determine heave, pitch and roll. Three pots would be sufficient to obtain this result, the fourth is for redundancy and consistency check, or allows to calculate the quantities with error estimates.
Valves in the pipes connecting the HLS sensors allow to operate each of the 12 sectors independently or the storage ring as a whole.
Currently the HLS system is suffering from various drifts which seem related to biological activities in the humid environment of the pipe system. An improvement of the system by the manufacturing company is expected for the end of 2001.

Horizontal Positioning System

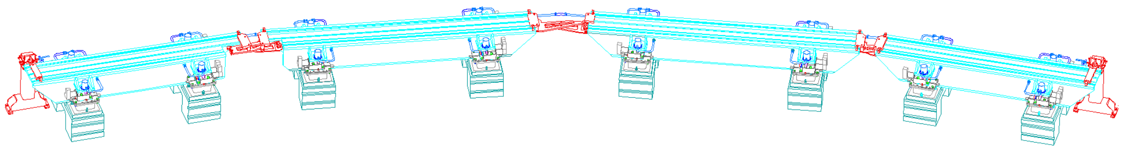

Figure 2: Four girders forming one sector. HPS sensors between adjacent girders and between end girders and sector terminating monuments are shown in red colour.

The novel horizontal positioning system (HPS) based on digital encoders mounted on lever arms touching the adjacent girders, resp. fixed monuments as shown in figure 2, allows to obtain sway and yaw of the girders. The evaluation has to be done for a whole sector at once, since the HPS reads only relative distances between girders.
Mathematically, the HPS system for a chain of N girders (N = 4 in case of SLS) is represented by a 2N×2N linear system with a 4-diagonal matrix relating the N sways and N yaws of the N girders to the sensor readouts on both sides of each girder and on the adjacent girders. Roll and pitch of the girder also affect the sensor readouts and thus have to be measured in advance by means of the HLS system.
The HPS sensors are digital linear encoders of ± 2.5 mm range and 0.5 µm resolution. The interface electronics for integration of the HPS into the EPICS control system has been developed at PSI.
The HPS shows excellent reproducibility and precision. Data are continuously archived in the Oracle Database. However, as long as the HLS is not yet operational, the HPS readouts can not be evaluated.

Positioning Monitoring system

One or two of the 72 beam position monitors (BPM) of the storage ring are mounted rigidly on each of the 48 girders. Naturally, the BPMs are also rigidly embedded in the vacuum chamber. Due to thermal expansions the vacuum chamber will apply forces to the BPM supports leading to movements relative to the girder. The vacuum chamber however does not touch the magnet poles, thus the magnets will keep their positions relative to the girder. In order to subtract offsets due to BPM motions from the BPM readings the BPM positioning monitoring system (POMS) based on the same type of digital encoder like the HPS, continuously measures the location of each BPM relative to an adjacent quadrupole. Position changes in the order of some 10 μm have been recorded in correlation to variations of the beam current between 0 and 200 mA [5].

Beam based Alignment

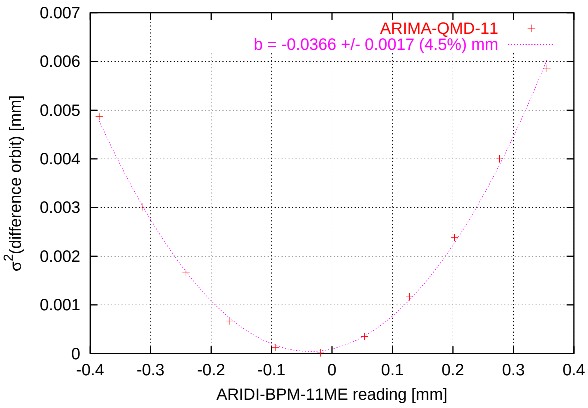

Figure 3: Beam based alignment of BPM 11ME

The initial calibration of the POMS has to be done by the procedure commonly referred to as beam based alignment (BBA), which actually means beam based BPM calibration: The variance of the difference orbit obtained when varying a quadrupole adjacent to the BPM is recorded as a function of the BPM reading. Variation of the amplitude of a local bump over the BPM/quadrupole pair then gives a parabola of the orbit variances with the minimum indicating the BPM offset relative to the quadrupole. A typical measurement is shown in figure 3. If there is a substantial phase advance between BPM and quadrupole, – as it is in case of the SLS low emittance lattice –, the local bump will lead to different beam excursions in BPM and quadrupole and the evaluation thus has to be modified based on the model. This work is in progress currently. Since there are 174 quadrupoles but only 72 BPMs, redundant information can be exploited to obtain a consistent and precise BBA survey. BBA data acquisition is straightforward at SLS, since every quadrupole has its own power supply.

Beam based Girder Alignment

Usually, the closed orbit is corrected by setting the appropriate currents in the 72 horizontal and 72 vertical corrector magnets (which are additional coils in the sextupoles). The possibility to move the girders enables us to perform an orbit correction by means of girder realignments. This procedure we call beam based girder alignment (BBGA).

Each girder provides two horizontal and vertical correctors corresponding to elongations of its ends, given by $x_{2n/2n+1} = u_n \pm ½L\eta_n$ and $y_{2n/2n+1} = v_n \pm ½L\chi_n$. 48 girders in SLS thus provide 96 "correctors", sufficient to correct the orbit in the 72 BPMs.

The standard singular value decomposition (SVD) orbit correction procedures can be applied in exactly the same way to the girder "correctors": Figure 5 shows the girder response matrices, i.e. the BPM responses to variations of a single "corrector", and the correction matrices obtained as pseudo inverse from SVD, i.e. the required "corrector" settings to obtain displacements in single BPMs. Since the girders extend over several magnets and up to two BPMs, the corrector matrices are not tridiagonal as the common matrices for magnetic correctors [6], but contain more non-diagonal elements.

Nevertheless the orbit correction works quite well as shown in figure 6: Real data of the bare orbit (i.e. all correctors switched off) of SLS in standard operation mode were used to calculate the required girder movements for orbit correction: In the vertical, the orbit correction is completely done by the girders. In the horizontal, filtering of the SVD weighting factors was required due to some degeneracy of the correction matrix, leaving 60 weighting factors and thus some residual horizontal orbit after girder alignment, which has to be corrected by the magnetic correctors. Nevertheless 72% of the horizontal and 100% of the vertical corrector magnet strengths can be saved. These results from a simulation using real data encourage us to set the girders accordingly during the next shutdown period in October 2001.

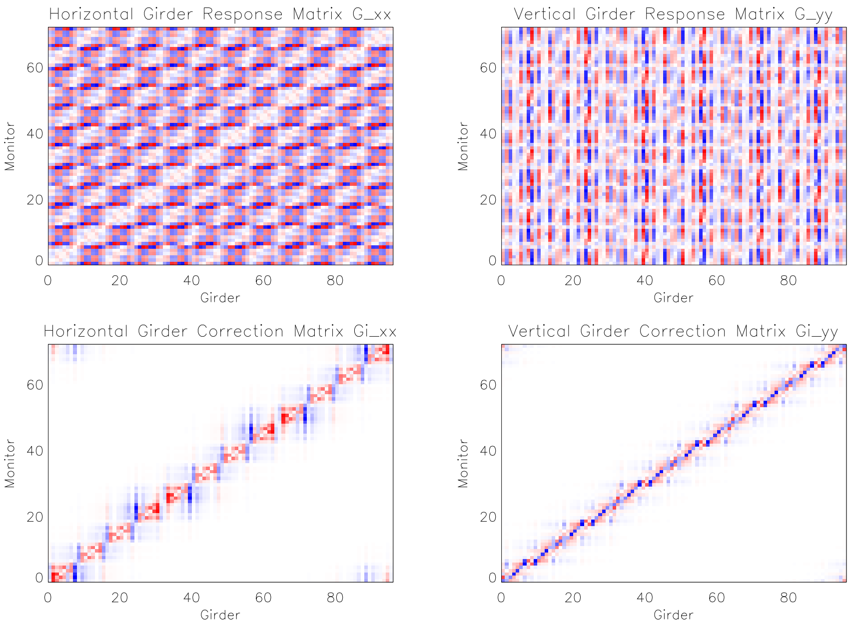

Figure 5: Girder response and correction matrices: Each "corrector" corresponds to the elongation of the end of a girder. 48 girders thus provide 96 horizontal and vertical "correctors".
(Colour saturation corresponds to matrix element value, red is positive.)

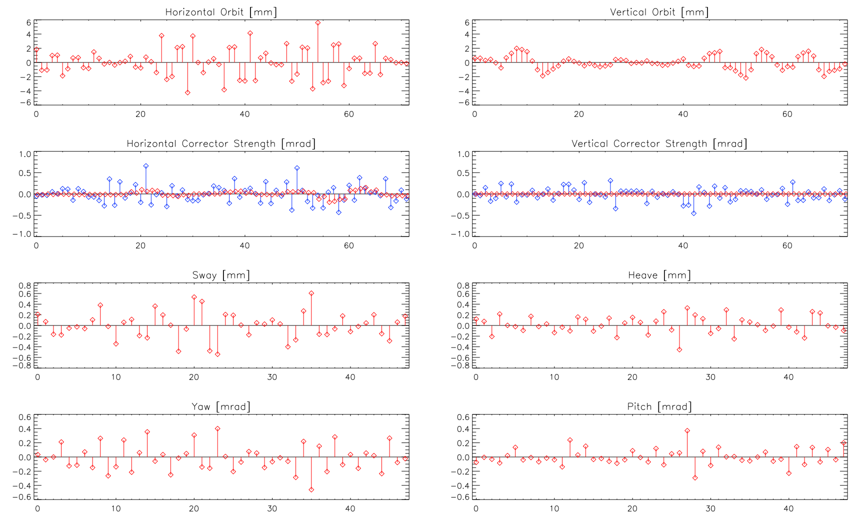

Figure 6: Beam based girder alignment: The upper row shows the measured bare orbit (i.e. all magnetic correctors switched off) of SLS in standard operation mode. The second row shows in blue the magnetic corrector settings for orbit correction. Beam based girder alignment requires to set sway, heave, yaw and pitch of the girders as shown in the third and fourth row. Afterwards the magnetic correctors are powered to suppress any residual orbits, these values are shown in red in the second row. The simulation indicates, that 72% of horizontal and 100% of vertical magnetic corrector strength will be saved by beam based girder alignment.

2 BEAM STABILITY

A worst case estimate of the seismic noise on the orbit gave 25 µm for the horizontal, resp. 15 µm for the vertical at 30 Hz, and 7.5 µm, resp. 1.5 µm at 60 Hz [7]. Attenuations by the fast orbit feedback system of 55dB, resp. 35dB at 30 Hz, resp. 60 Hz reduce this to values much smaller than the 1 µm orbit stability requirement from the beamline users.
Noise measurements done so far without orbit feedback yet running gave following results for the maximum orbit anywhere in the machine:

< 1 µm at 3 Hz from the booster ramp crosstalk to the storage ring,
< 3 µm around 16 Hz and 24 Hz from girder mechanical resonances,
< 3 µm at 50 Hz and odd harmonics in dispersive regions indicating a 10 ppm energy jitter from RF.
100 Hz orbit correction with the attenuation factors mentioned above thus will be able to achieve a beam according to quietness requirements.

Orbit Feedback

The orbit feedback is presently running at 1 Hz as repeated automatic orbit correction. Even in this mode it is quite useful, since it keeps the orbit to the micron at reference while changing the tune slightly, opening and closing insertions, etc.

Figure 7 displays the activity of the orbit feedback: Horizontal and vertical rms orbits are kept at 1.5 µm, resp. 1.8 µm rms. The horizontal rms orbit however grows slowly due to a drift of the central frequency (= harmonic number × speed of light / ring circumference) in the order of –10 Hz/hr. If the central frequency exceeds some predefined margin, the orbit feedback automatically adjusts the RF frequency to the central frequency, thus correcting the mean horizontal orbit to zero. The drift of the central frequency is related to slow thermal effects due to variations of beam current.

The 100 Hz fast orbit feedback presently under installation is based on 12 DSP stations calculating corrector currents from BPM signals independently for each sector by means of the corresponding sector submatrix of the correction matrix. Since the corrector matrix is of tridiagonal structure, 12 local sector corrections are in fact equivalent to one global ring correction. However, the sector DSPs exchange information with their neighbors, since they need at least two BPMs from the adjacent sector in order to control all their correctors. Actually, they even get data from all neighbor sector BPMs in order to be able to compensate for disabled BPMs. A slow central unit sends updates of the correction matrices to the 12 DSPs. Operation of the 100 Hz feedback is scheduled for end of 2001.

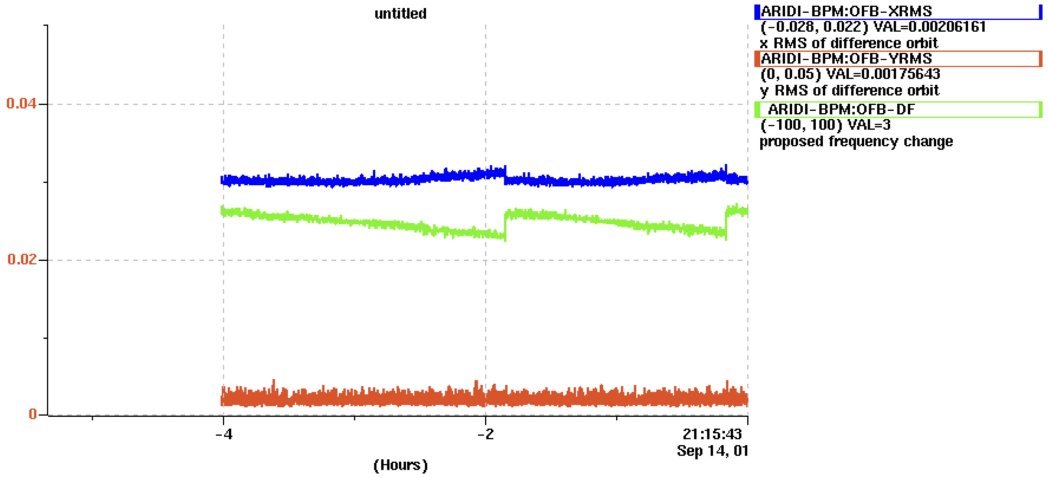

Figure 7: Orbit feedback. from top to bottom: horizontal rms orbit (note axis offset!), central frequency, vertical rms orbit. The orbit feedback keeps the rms orbits on a micron level. When the drift of the central frequency, derived from the horizontal mean orbit, exceeds some predefined margin the RF frequency is adjusted.

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