SLAC-PUB-9720
April 2003

DYNAMIC ALIGNMENT AT SLS

V.Schlott, R.Kramert, M.Rohrer, A.Streun, P.Wiegand, S.Zelenika, PSI, Villigen, Switzerland
R.Ruland, SLAC, Menlo Park, USA; E.Meier, Ingenieurbüro Meier, Winterthur, Switzerland

Abstract

The relative alignment of components in the storage ring of the Swiss Light Source (SLS) is guaranteed by mechanical means. The magnets are rigidly fixed 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 and thus establish virtual train links between the girders, located near the bending magnet centres. Keeping the distortion of the storage ring geometry within a tolerance of ±100 µm in order to guarantee sufficient dynamic apertures, requires continuous monitoring and correction of the girder locations. Two monitoring systems for the horizontal and the vertical direction will be installed to measure displacements of the train link between girders, which are due to ground settings and temperature effects: The hydrostatic levelling system (HLS) gives an absolute vertical reference, while the horizontal positioning system (HPS), which employs low cost linear encoders with sub-micron resolution, measures relative horizontal movements. The girder mover system based on five DC motors per girder allows a dynamic realignment of the storage ring within a working window of more than ±1 mm for girder translations and ±1 mrad for rotations. We will describe both monitoring systems (HLS and HPS) as well as the applied correction scheme based on the girder movers. We also show simulations indicating that beam based girder alignment takes care of most of the static closed orbit correction.

1 SLS GIRDERS AND MOVER SYSTEM

The SLS storage ring girders have been designed by means of FEM numerical simulations to provide an eigenfrequency spectrum, which does not coincide with the main sources of ground motion at SLS. The results of the numerical modal model have been verified during a vibration measurement campaign [1], showing maximum vibration amplitudes of less than 20 nm in a frequency range between 20 Hz and 35 Hz. The upper part of the girders is designed to provide ground horizontal and vertical reference surfaces with a precision of ±15 µm over the whole girder length of 3.7 m respectively 4.5 m. Magnets and BPM supports, which are also machined with comparable tolerances are directly mounted on these alignment rails without any further individual fiducialising and surveying. A mover system using eccentric cam shaft kinematic drives allows hysteresis-free positioning of the

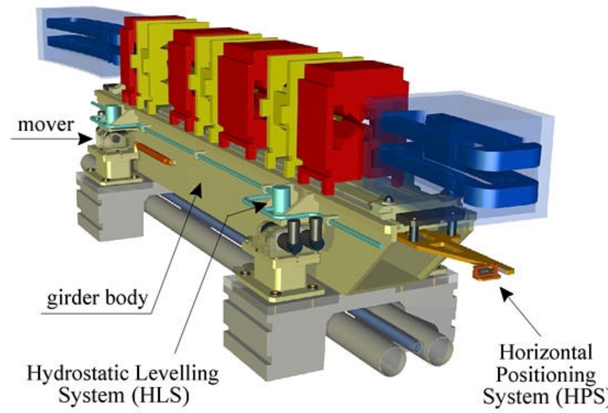

Figure 1: SLS storage ring girder assembly

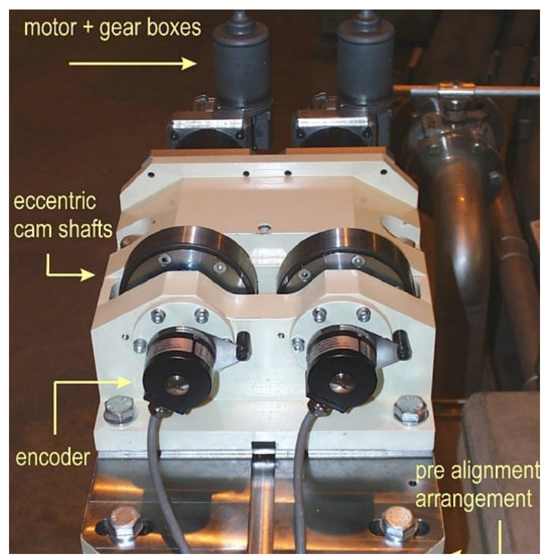

Figure 2: Mover system for SLS storage ring girders

complete assembly. Five DC motors with worm gears provide a minimum positioning resolution of ±2 mm within a motion range of ±2.5 mm in vertical and ±3.5 mm in horizontal direction for each mover. Each girder can be moved in five degrees of freedom: sway and heave (horizontal and vertical displacements), pitch, yaw and roll (rotations around horizontal, vertical and longitudinal axis). Solutions for the excenter angles exist for the whole girder assembly within a working window of more than ±1 mm and ±1 mrad for any combination of misalignments, which might be caused by thermal and geological horizontal and vertical disturbances. Conversely the girder position as function of any combination of excenter angles is uniquely defined by a 5×5 linear sys-

Work supported in part by the Department of Energy contract DE-AC03-76SF00515.
Stanford Linear Accelerator Center, Stanford University, Stanford, CA 94309
Presented at the 7th European Particle Accelerator Conference (EPAC 2000),
Vienna, Austria, June 26-30, 2000

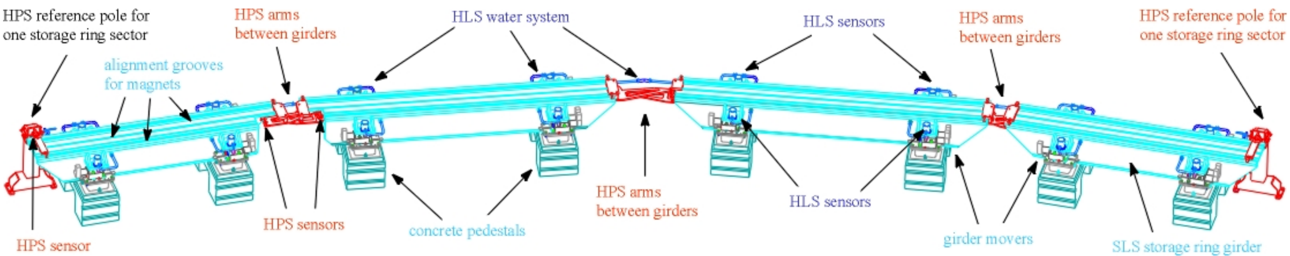

Figure 3: HLS (blue) and HPS (red) systems overview over one sector (corresponds to one TBA) of the SLS storage ring. Magnets and BPMs mounted on the alignment rails at the girder surface are not shown.

tem [2]. Tests on the real girders proved that the motions are as expected [3].

2 HYDROSTATIC LEVELING SYSTEM

The hydrostatic levelling system (HLS) provides an absolute vertical reference for the SLS storage ring. The system was conceived to monitor any relative and global vertical position change with a resolution of < 2 µm and within a working window of 2.5 mm. Capacitive proximity gauge based sensors are housed in stainless steel boxes of 100 mm diameter. The dimensions of the measuring pots have been optimised for maximum sensitivity and minimum influence of thermal and vibrational effects. Four pots per girder are positioned exactly above the movers to measure heave, pitch and roll and to monitor corrections executed by the girder mover system. A total of 192 sensors are installed around the SLS storage ring. They are connected by a stainless steel pipe of 25 mm diameter, which is half filled with demineralised water.

Preliminary tests, which have been performed during the SLS storage ring installation, indicate a reproducibility of the HLS and girder mover system of better than 5 µm. A cyclic movement of one side of a girder by 1 mm is shown in figure 5. In the near future, a connection between accelerator and experimental areas is foreseen through the accelerator tunnel wall. It will thus provide a global vertical reference for all SLS installations and will allow compensation of vertical drifts between storage ring and beamlines.

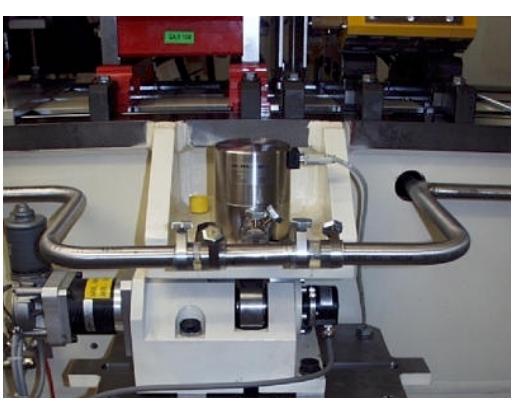

Figure 4: HLS sensor with water pipe connection.

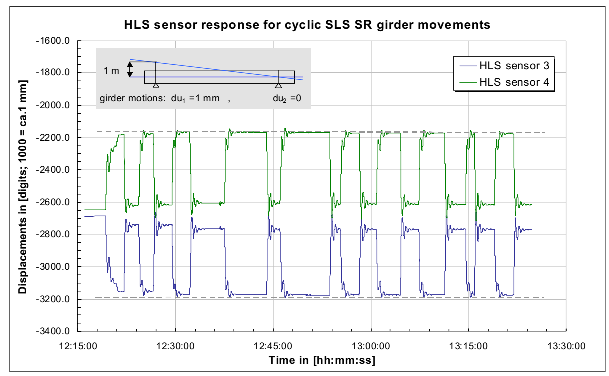

Figure 5: HLS sensor readout for cyclic movement of a SLS storage ring girder on one side by 1 mm (see insert).

3 HORIZONTAL POSITIONING SYSTEM

For measurements of vertical motions gravity provides an absolute reference used by the HLS. Due to lack of a comparable reference in the horizontal, the horizontal positioning system (HPS) as shown in figure 3 measures only relative movements between adjacent girders or between a girder and a reference pole on each side of a sector. These reference poles are extremely stiff and were constructed for minimal thermal expansion. Their positions are initially determined by the SLS survey and alignment group and checked during shut down periods. At SLS four girders extending over one of the 12 triple bend achromat (TBA) structures form a chain containing 6 HPS sensors between girders and two at the outside reference poles. Thus sway and yaw of each of the girder can be calculated from the sensor readouts.

A total of 96 (8 per sector) digital, linear encoders of type Renishaw RGH24Z50A00A with 0.5 µm resolution are used as position sensors. They are housed in dial gauges, which have ± 2.5 mm measuring range. A unique interface electronics for encoders has been developed at SLS to fully integrate the HLS into the EPICS control system. The same interface is used to read out the absolute rotary encoders of the girder mover system and the linear encoders of the BPM position monitoring system (POMS), which measures mechanical drifts of the SLS storage ring BPM chambers. Measurements of the HPS in reference to a HP laser interferometer were performed at the SLS girder test facility. Both parallel and angular displacements of girders in the range between 1 mm and 10 µm could be reproducibly measured within the resolution of the system. Figure 7 shows examples for measurements of parallel displacements in reference to a HP laser interferometer.

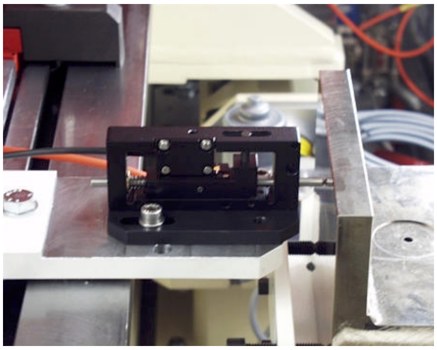

Figure 6: HPS sensor touching reference pole.

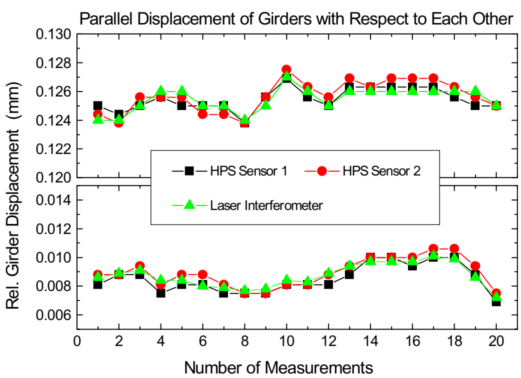

Figure 7: Parallel displacements of SLS storage ring girders, measured with HPS system at SLS girder test facility in reference to HP laser interferometer.

Mathematically the HPS system as shown in figure 3 for a chain of N girders (in case of SLS: N = 4) 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 HPS sensor readouts on both sides of each girder and on the adjacent girders. Roll and pitch also affect the sensor readouts and thus have to be measured in advance by means of the HLS system [2].

4 BEAM BASED GIRDER ALIGNMENT

Static and dynamic closed orbit correction in the SLS storage ring is performed by adjusting 72 horizontal and vertical corrector magnets to center the beam in 72 BPMs [4]. Our simulations indicate that it should be possible to apply the same procedure to girder alignment by treating the girder misalignments like correctors magnets: Misalignment of a girder will *somehow* affect the beam because it will pass the magnets on the girder off-axis and thus receive some kick. The "correctors" defined in this way are displacements and rotations of the girders. From 48 girders in SLS we thus get 96 horizontal and vertical "correctors". We implemented this procedure into the TRACY beam dynamics code [5] using the SVD (singular value decomposition) module from CERNLIB.

As a first step the orbit correction was done in the classic way by excitation of the corrector magnets. In a second step the correctors were reset to zero while keeping the same set of random seeds, and the girder "correctors" were used to correct the beam. Afterwards the corrector magnets were activated again to suppress any residual orbit left over from girder alignment. Finally the values of corrector strength from first step, i.e. without, and second step, i.e. with beam based girder alignment were compared. Results are shown in figure 8.

In the vertical plane the procedure works perfectly: The correctors remained at zero strength after girder alignment, i.e. all static vertical closed orbit correction is fully covered by girder alignment. In the horizontal the correction matrix became ill-conditioned probably due to betatron phase advances close to 180° over some of the girders (at SLS the horizontal tune is much larger than the vertical tune). Filtering of the SVD weight factors left 60 efficient "correctors" and lead to a robust girder realignment still reducing the corrector magnet strengths by a factor of four. There is little change in the rms and maximum girder misalignments before and after realignment, however the individual values were reshuffled turning a random into an optimum pattern of misalignments. Our results indicate, that beam based girder alignment is able to take care of most of the static closed orbit correction.

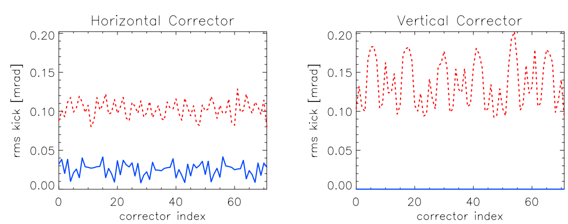

Figure 8: Beam based girder alignment: rms corrector magnet strengths before (red dotted) and after (blue solid) closed orbit correction through girder alignment. 200 random seeds for misalignments were generated and corrected: The application of random errors assumed partial train links over four girders with rms (2σ cut) displacement errors of 300 µm for the [virtual] girder joints, 100 µm for the joint play and 50 µm for magnets and BPMs relative to the girder [2].

REFERENCES

[1] P.Wiegand, "SLS SR girder, vibration and modal analysis tests", SLS-TME-TA-2000-0153

[2] A.Streun, "Algorithms for dynamic alignment of the SLS storage ring girders", SLS-TME-TA-2000-0152

[3] P.Wiegand, "SLS SR girder mover: Test of the control system", SLS-TME-TA-2000-0145

[4] M.Böge et al., "Fast closed orbit correction in the SLS storage ring", PAC 99, New York, p.1129

[5] M.Böge, "Update on TRACY-2 documentation", SLS-TME-TA-1999-0002