VERTICAL ALIGNMENT OF THE SLS 2.0 STORAGE RING

M. Böge*, M. Aiba, F. Armborst, M. Brinkmann, K. Dreyer,
T. Hoewler, F. Maier, J. Kallestrup,M. Wurm
PSI Center for Accelerator Science and Engineering, Villigen, Switzerland

Abstract

The alignment of girders and individual magnetic elements according to the tight design specifications is of paramount importance for achieving the ultimate performance of the SLS 2.0 storage ring (SR) which is consisting of a large number of SR optics defining permanent magnets. As a result, alignment errors can easily overstrain the very limited capabilities of the electromagnetic dipole corrector magnets. In order to enable a fast realignment during commissioning the girders are vertically remotely adjustable allowing for a realignment within ±0.5 mm (backed by simulations) with stored beam and running fast orbit feedback based on previously taken survey data (Beam-Assisted Girder Alignment). A linear encoder based vertical positioning system monitors the relative girder-to-girder motion. In addition, the orbit correction system helps to identify errors of individual magnets on the girders.

INTRODUCTION

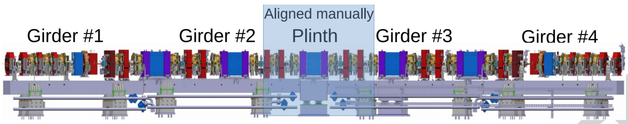

Figure 1: Layout of one arc consisting of 4 girders with vertical remote control and a central plinth with manual magnet alignment capability only.

Between September 2023 and December 2024 the old SLS storage ring was exchanged by the new SLS 2.0 ring [1] which provides a much lower emittance of 150 pm at 2.7 GeV and is installed in the existing tunnel [2]. The combination of lower emittance and higher beam energy provides a factor 60 increase of hard X-ray brightness (>10 keV), which will be further enhanced by means of new undulators of shorter period. The range of radiation sources from period elliptic undulators to superconducting superbends of up to 5 T peak field will support experiments spanning photon energy ranges from 6 eV to 80 keV.

At the beginning of 2025 SLS 2.0 underwent successful commissioning [3] followed by first user operation at the design current of 400 mA at the end of the same year [4] [5].

The improvements in lattice performance also require a very precise alignment of the ≈1000 magnet components, which are distributed over the 288 m circumference on 60 support structures (48 girders and 12 plinths) forming 12 nearly identical arcs (see Figure 1) and 12 straight sections of 3 different lengths. The alignment tolerances are determined by the correctability of the imperfect lattice established by simulations [1]: girder absolute 60 μm RMS, girder-to-girder 20 μm RMS, element-to-element 30 μm RMS, Component roll 300 μrad RMS with a 2σ cut.

* Michael.Boege@psi.ch

INITIAL ALIGNMENT

The alignment process was distributed over multiple stages of the upgrade. The starting point was a solid reference network established for SLS 1.0 in 1999 which was constantly maintained and updated for >20 years to keep measurements around the ring as precise as possible. This network consists of 100 wall references and 53 floor references. In January 2025, the survey network for the final alignment was measured with 55 laser tracker positions and then calculated to get an up-to-date reference for the final alignment campaign [6].

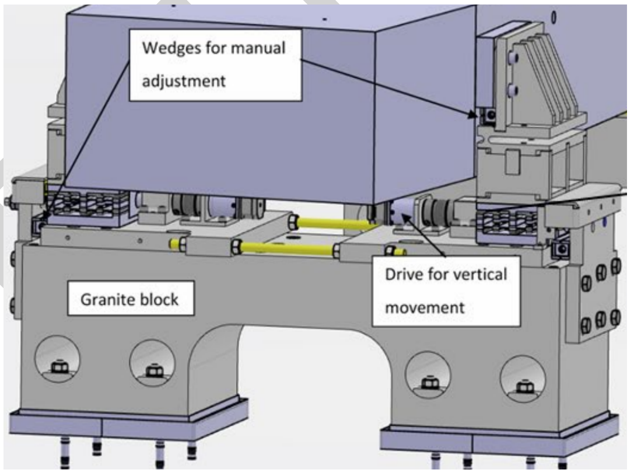

Figure 2: Girder alignment mechanism with remote controlled satellite roller screws with vertical adjustment steps of 1 nm and wedges for manual adjustments [6].

All magnets were measured on measurement benches with vibrating and moving wires defining every magnetic centre with a precision of <30 μm RMS to its fiducials. For some delicate magnet assemblies like the sextupole-quadrupole corrector combinations used for BBA [7] or some delicate permanent magnet combinations the allowed tolerance went down to <10 μm.

After the assembly in the pre-assembly hall with temperature variations <5°C daily, the first step of the initial alignment was the positioning of 23 magnets on the ≈4 m long girders in a temperature controlled environment at 25±0.5°C. The pre-aligned girders were then installed in the tunnel on pre-levelled floor plates providing ±0.5 mm global level precision in order to minimize the successive vertical adjustment with the dedicated wedges depicted in Figure 2.

Girders were aligned to the best precision possible given the conditions during the machine construction in 2024. Temperature variations of ≈4°C led to expected and measured position variations of ≈70 μm at the beam height of 1.4 m. The missing weight of ≈4000 t of 400 concrete roof beams during installation had a significant effect on the reference network which does not deform uniformly elastically under load change. Thus errors in the alignment due to uneven deformation were expected.

FINAL ALIGNMENT

The commissioning started in January 2025 knowing that especially the vertical alignment of the girders would be far out of specification. After the closure of the tunnel roof a complete magnet survey was carried out which as a by-product revealed the girder misalignments.

Figure 3 depicts the 48 girder + 12 plinth fits (blue squares) in the vertical plane with respect to the alignment network ranging from −300 μm to +350 μm and the location of the source points (SP)(red dots) in the straight sections. The displacement of the girders adjacent to the SPs would result in significant beam steering at the corresponding beamlines. The dipole beamlines taking light from the triplets mounted on the solid granite plinths in the centre of the arcs (see Figure 1) are also affected.

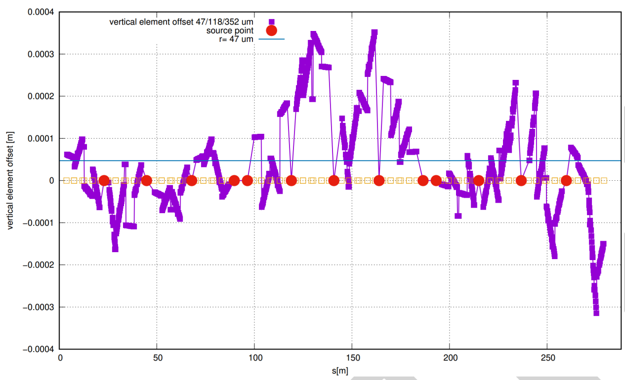

Figure 3: Vertical girder fits after initial alignment (blue squares) with respect to the alignment network ranging from −300 μm to +350 μm. The location of the source points in the straight sections is indicated by red dots.

These fits were fed into an optics program in order to calculate the resulting vertical orbit deviation (blue line) after "hard" (no SVD eigenvalue cut) correction to the centres of 115 monitors (blue squares), which are shifted together with all magnets on the girders, by utilizing their adjacent vertical dipole correctors (see Figure 4). The resulting corrector pattern (green impulses) reflects (with the opposite sign) the expected changes of the correctors when aligning the girders to the reference network represented by the zero line in the graph. The corrector values are ranging from −250 μrad to +250 μrad, which corresponds to ≈ half of the total corrector strength, which illustrates the potential of vertical realignment in terms of corrector strength reduction.

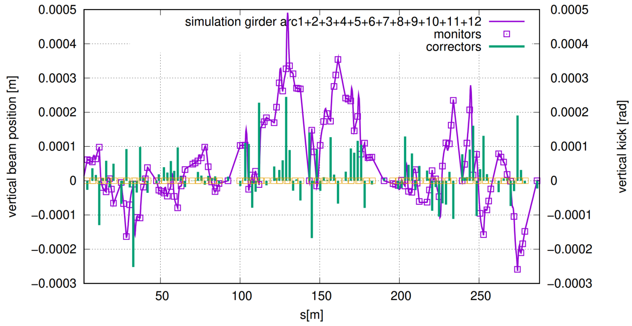

Figure 4: Vertical orbit deviation (blue line) when "hard" correcting to the centres of 115 monitors (blue squares), shifted together with all magnets on the girders, by utilizing their adjacent vertical dipole correctors (green impulses).

The simulation results can be used to predict the changes of correctors when realigning girders remotely with stored beam and fast orbit feedback [8] running, which forces the vertical orbit to the centre of the monitors by adjusting the correctors in the feedback loop. This method of "Beam-Assisted Girder Alignment (BAGA)" was already successfully deployed at SLS 1.0 in 2011 [9] which eventually led to the decision to implement the vertical remote control capability of the girders at SLS 2.0.

Figure 5 depicts the controls interface for the remote girder adjustment. Motors and encoders provide a 1 μm positioning resolution of the girder feet. Corresponding heave and pitch values are displayed. The adjustment range is limited to ±500 μm. The roll is kept constant. In addition to the readback of the motor encoders the relative positions of adjacent girders and the central plinth are monitored by a linear encoder based vertical positioning system (VPS).

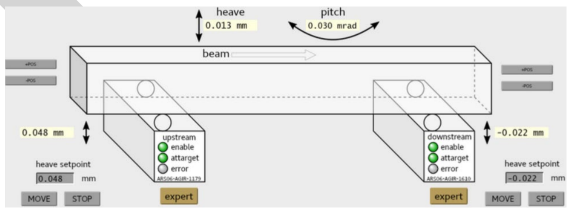

Figure 5: Controls interface for the remote vertical girder alignment. Motors and encoders provide a 1 μm positioning resolution of the girder feet. Corresponding heave and pitch values are calculated.

As an example for a BAGA result the corrector changes in the 8th arc are shown in Figure 6. The kick change prediction for the involved 9 arc correctors (green crosses) is overlayed with the observed current changes (blue pluses). The agreement is excellent within the expected reproducibility of the corrector field as a function of current. In this case the total RMS corrector strength was reduced from 100 to 75 μrad.

Figure 7 summarizes the 8 motor encoder setpoints of 4 girders/arc for all 12 arcs (0-11) after the final vertical alignment. This result should be compared to the initial girder misalignments shown in Figure 3.

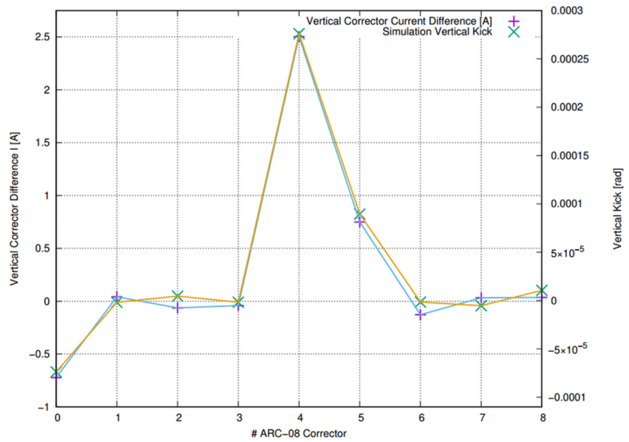

Figure 6: BAGA result for corrector changes in the 8th arc. The kick change prediction for the 9 arc correctors (green crosses) is overlayed with the observed current changes (blue pluses).

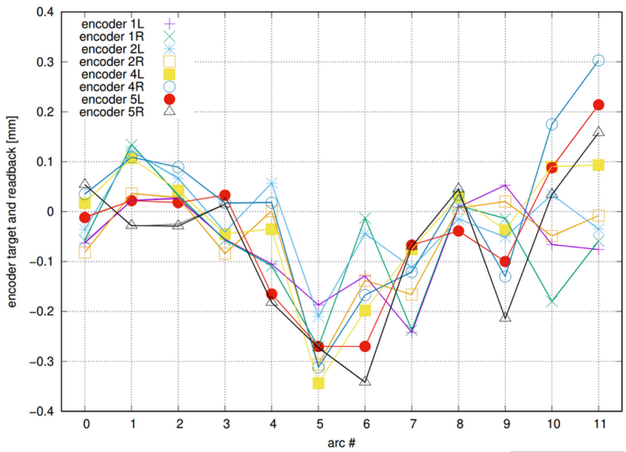

Figure 7: Motor encoder setpoints of 4 girders/arc for all 12 arcs (0-11) after the final vertical alignment.

The complete vertical alignment of 48 girders was carried out within a few dedicated machine shifts at 400 mA in Top-Up mode. No tunnel access was needed. The beam could be kept during the alignment, making recommissioning after manual alignment in the tunnel obsolete. The beam positions have been put on the zero line of the reference network for all beamlines. Corrector excitations due to girder misalignments have been largely removed. The total vertical RMS kick could be reduced from 130 μrad to 118 μrad (90%). In some arcs it could be reduced to 60% of its original value.

Figure 8 shows the histogram of the final kick distribution after BAGA (red bars). The blue line corresponds to the kick distribution expected from simulations for the nominal errors. It can clearly be seen that both distributions agree quite well for positive kicks. For negative kicks a few outliers of ≈ -250 μrad are dominating the distribution after BAGA. Some of these outliers could be traced back to large individual magnet assembly misalignments. The realignment of 3 duplets in straights 3,9 and 11 and one triplet in the 12th arc reduced the RMS kick to 111 μrad.

CONCLUSION

The final vertical alignment of 48 girders was performed within a few machine development shifts with stored beam using the remote control capability of the girders. The re-alignment was guided and verified by simulations and carried out as part of the machine commssioning and was therefore without major interference with beamline commissioning.

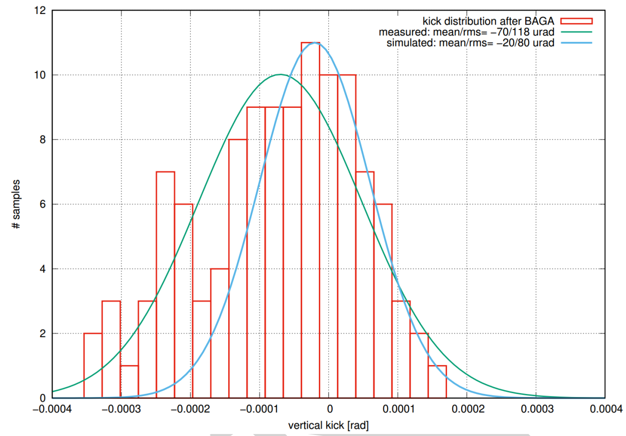

Figure 8: Histogram of the final kick distribution after BAGA (red bars) and the kick distribution expected from simulation for the nominal errors (blue line).

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