STATUS OF THE SLS ALIGNMENT SYSTEM

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ABSTRACT

The Swiss Light Source (SLS), a third generation light source, is a high brilliance machine designed for extremely low emittance, which is, therefore, highly sensitive to alignment errors. The SLS consists of linac, booster, storage ring, transfer line and beam lines. Its several hundreds of magnets and other components were aligned in 2000. A relative accuracy of one tenth of millimeter has been achieved for most magnets and other important components. At the first attempt the injected beam immediately passed through both, the booster in July and the storage ring in December 2000 with all correctors switched off. On the third day of storage ring commissioning, a 2 mA electron beam was stored with a lifetime of 8.5 minutes. All global machine parameters, as energy, current and emittance were achieved according to specifications in 2001. The first images from experiments of the four beam lines have been taken within a few days after installation and alignment. Several new beam lines will be installed in the near future. The SLS alignment system will be presented in this paper.

1. OVERVIEW

The SLS is a medium energy range light source that provides light with high brilliance in the regime from VUV to hard X-rays. Soon after approval by the parliament in 1997 to build it at the Paul Scherrer Institut in Villigen, Switzerland, it was forecasted that first light on sample would be on august 1, 2001 [1]. Ground breaking of the SLS building started as scheduled on June 2nd 1998. Only one year after this date, July 1999 the SLS building was ready for machine installation. In spring of 1999 a laser tracker LTD500 was delivered and tested as a main instrument for survey and alignment [2]. At the beginning of the year 2000, the transfer line from linac to the booster was installed inside the linac tunnel. Assembly of the linac was completed in February 2000. First beam at 100 MeV from the linac was reached in March and the acceptance tests were concluded with the achievement of all specified parameters in April. The first booster magnets

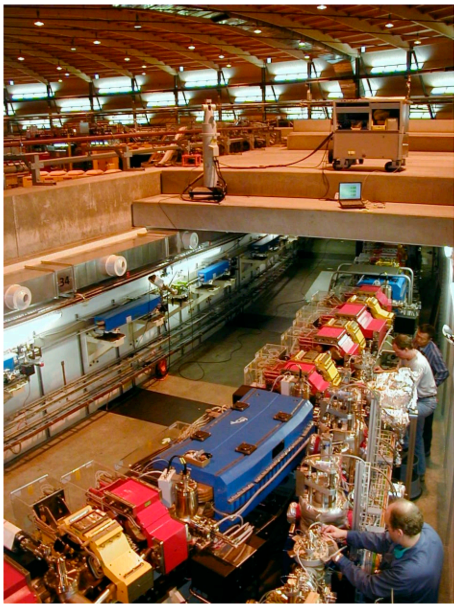

Fig.1: The booster, the storage ring and the front end during alignment of the front end

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were installed in the ring tunnel at the end of October 1999. Five months later the installation process for these magnets was finished and commissioning could start as scheduled in the middle of 2000. Although the vacuum chamber cross-section is rather small (30 mm x 20 mm over the whole circumference) the first turn was reached without any of the 108 steering magnets switched on, indicating an excellent alignment of the booster [3]. The commissioning process went rather swiftly, and the design performance was reached by the end of September 2000. The major installations of the storage ring were concluded before booster commissioning in July 2000. The start of the storage ring commissioning was scheduled for the beginning of the January 2001. By end of the September 2000 it became clear that all the hardware and checkouts would be finished by the middle of December. It was then decided to advance the storage ring commissioning. The first injection tests were on December 12. After producing the first turn on December 13, a beam of 2 mA could be stored in the relaxed optics on December 15. Again, the beam was stored with no correctors turned on, which attested to the quality of the alignment of the storage ring components [4].

Insertion devices, front ends and other components of the 4 beam lines were aligned into their positions in the last two years. Figure 1 shows a part of the booster, the storage ring and a front ends. All global machine parameters, as energy, current and emittance were achieved according to specifications and beam lines started to take data in 2001. The first images from experiments have been taken within a few days after completion of installation and alignment.

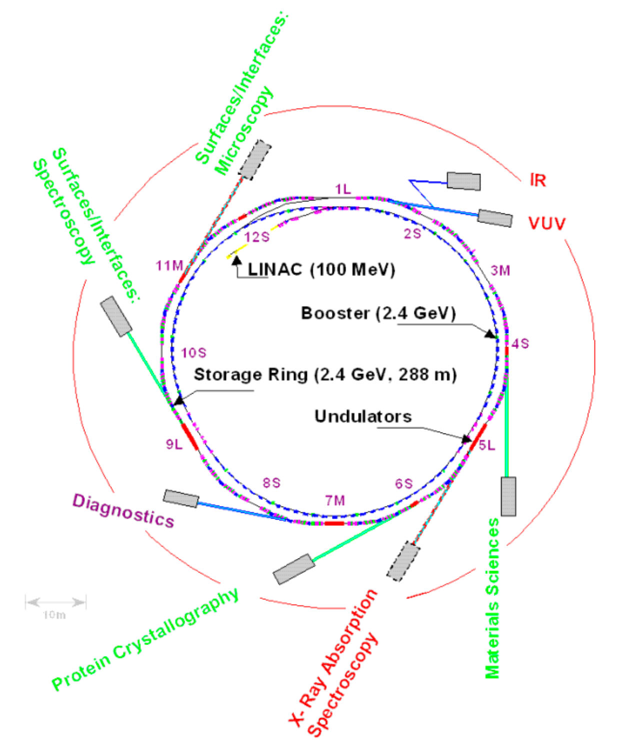

Fig. 2: SLS Layout

As part of an upgrade program, three central magnets of the triplet bend achromat structure of the storage ring will be replaced by super bends. Several new beam lines and new stations will be installed in the near future. Figure 2 shows the SLS layout.

2. TUNNEL NETWORK

From May 1999 to now, the tunnel network has been measured 6 times by Laser Tracker LT500. A precision level N3 instrument was used to measure the elevations of the tunnel network in May 1999. Figure 3 shows the tunnel network. At the same time, the network was measured with the LTD500 using the software Axyz. The measurements were performed for 53 stations nearby each floor reference.

In July 1999 the tunnel network was measured again only with LTD500. The standard deviation (1σ) of the second measurements was 0.079 mm. The tunnel network was measured in January 2000 for the 3^{rd} time. The shielding wall of the tunnel was completed. All wall references were fixed. Therefore the environmental conditions were better. The standard deviation (1σ) of the 3^{rd} measurements was 0.073 mm.

In August of 2000 and January of 2001 the tunnel alignment network was measured before and after the final alignment of the storage ring. The standard deviation (1σ) of the last two tunnel network measurements was 0.066 mm. A best result of the alignment network was reached because the environmental conditions became better and our measurement team got more experiences. Figure 4 shows vertical deformations of the tunnel floor from 1999 to 2002, which is less then 1 mm.

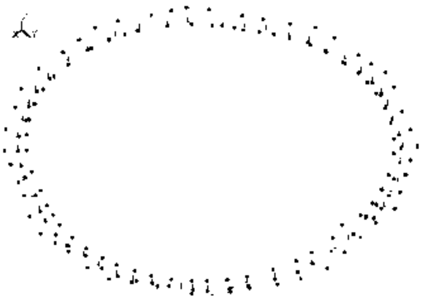

Fig.3: Tunnel Network

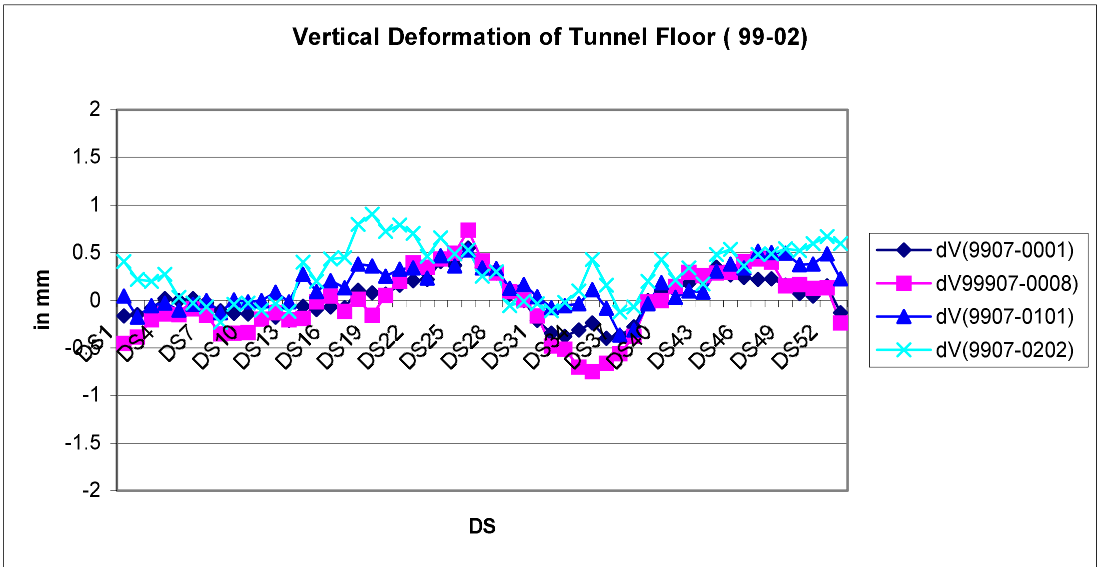

Fig. 4: Vertical Deformation of Tunnel Floor from 1999 to 2002

3. EXPERIMENT NETWORK

The network for the experimental area, shown in Figure 5, was measured for the first time using Theodolite TDA5005 in July 1999. The experiment area was free for survey at that time. The standard deviation (1σ) of the measurements was 0.352 mm.

The experiments network was measured in September 2001 by Theodolite TDA5005 and Laser tracker LTD500. Several areas of the experimental hall were covered. Many additional references ware added inside of the beam line hutch. Some temporary references have to be added. The standard deviation (1σ) of the measurements was 0.354 mm at this time. The maximum vertical deformation of the experiment floor from July 1999 to September 2001 is less then 3 mm, shown in figure 6.

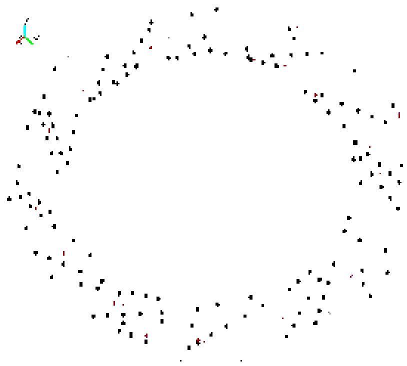

Fig. 5: SLS Experimental Network

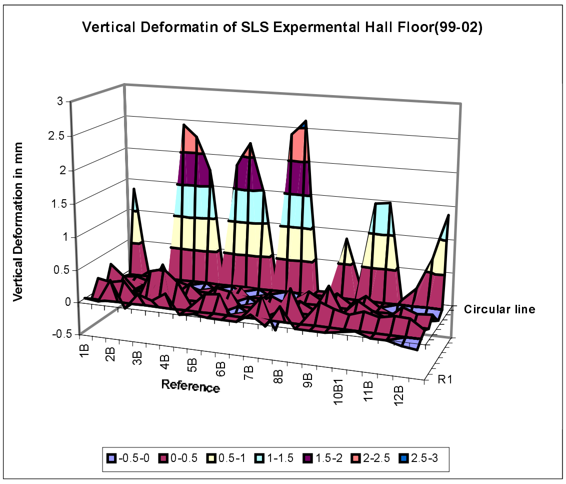

Fig. 6: Vertical Deformation of SLS Experimental Floor

4. ALIGNMENT OF THE STORAGE RING

All the quadrupoles and sextupoles of the storage ring are well fixed on girders. To ensure a smooth storage ring orbit at SLS, special attention was given to the alignment of the storage ring magnets. Measurements of the mechanical centers (magnet laminations) were done to verify the correct installation of the SLS storage ring magnets, using the laser tracker LTD500 [5].

Standard deviations of the positions of mechanical centers of the magnets in respect to positions of the girder references were 0.044 mm and 0.030 mm in the radial direction and in the vertical direction, individually shown in figure 7 and 8.

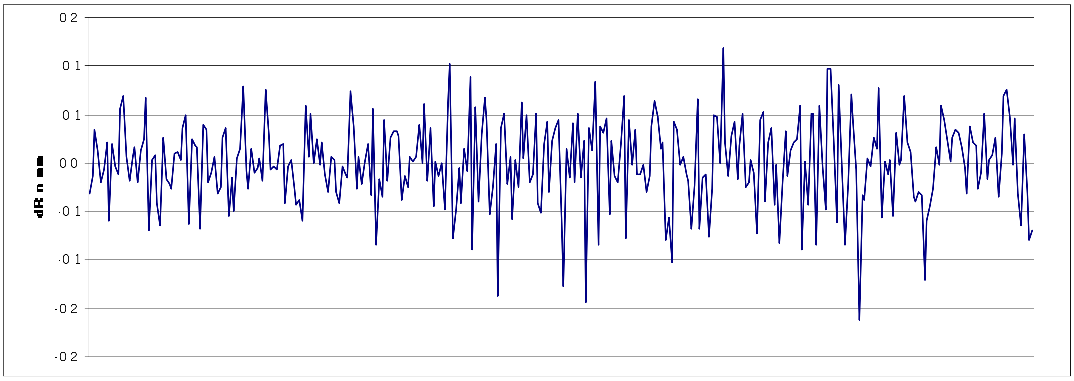

Fig. 7: Deviation dR of mechanical centers of SR quadrupoles and sextupoles magnets in respect to the positions of the girder references

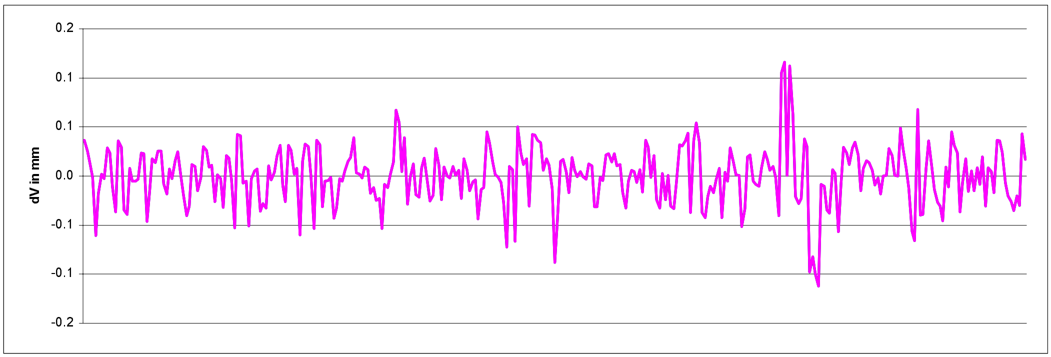

Fig. 8: Deviation dV of mechanical centers of SR quadrupoles and sextupoles

magnets in respect to the positions of the girder references.

In the meanwhile positions of the references of the magnets of the storage ring were measured and registered too.

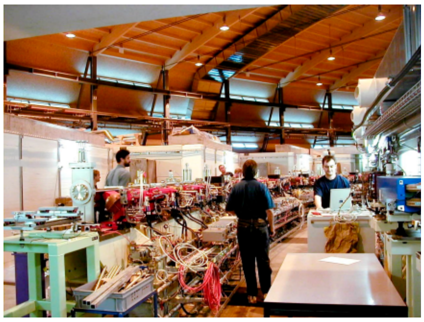

Fig. 9: Alignment of the SR SR

The SLS storage ring consists of 48 girders. Each girder is supported by 4 pedestals. The positions of the pedestals were pre-aligned. The positions of each girder are adjustable by 5 motors and a screw bar. All positions of the references of each girder and magnets on the girder were measured by laser tracker LTD500 in respect to the SLS alignment tunnel network.

The coordinates were exported from Axyz software to IDL software to calculate deviations of 6 freedoms of the girder. Then the girder was adjusted by 5 motors using a control box and the screw bar. Usually those operations were iterated 2 or 3 times until the standard deviations were less then 0.1 mm. Figure 10 shows the final alignment results of the reference positions of the SR magnet quadrupoles and sextupoles in December 2002.

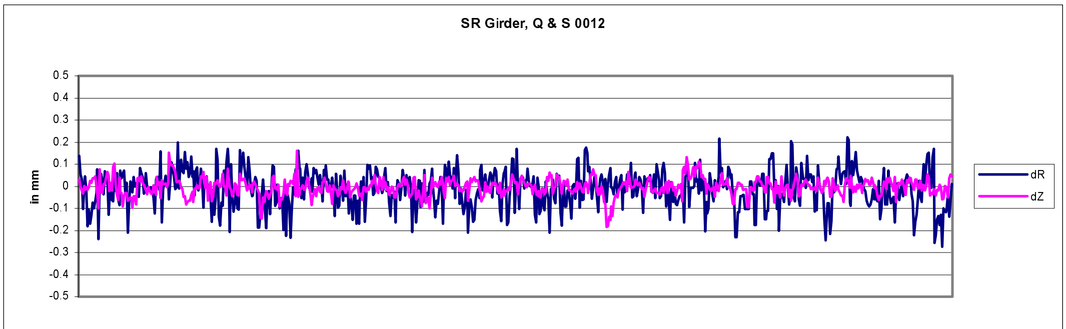

Fig. 10: Reference Positions of the SR magnet Quadrupole and Sextupole

The bending magnets are supported by 2 adjacent girders. The bending magnet was aligned immediately after the adjacent girders were aligned. The upper parts of the magnets of the storage ring were removed to insert the vacuum chambers. The vacuum chambers of the storage ring were aligned by laser tracker too. The magnets of the storage ring were re-aligned once after installation of the vacuum chambers before commissioning in November 2000. Main commissioning of the storage ring was done from January to July 2001. Several circumference measurements based on orbit correction or sextupole centering by variation of RF frequency confirmed the design value within 0.5 mm [6].

The top-up mode of machine operation was used successfully and is becoming the favourite operation mode for user runs. In year 2002 an average of 59 shifts per month is envisaged, wherefrom about 80% will be dedicated to user operation.

5. ALIGNMENT OF THE BEAM LINES

The important target of "photons on sample" at the SLS by August 2001 was met.

The four existing beam lines, the Materials Science Beam line(MS), the Protein Crystallography Beam line(PX), the Surfaces/interfaces Spectroscopy Beam line(SIS), and the Surfaces/Interfaces Microscopy Beam line(SIM), consist of insertion devices, front ends, monochromators, mirror boxes, slits, and experimental stations.

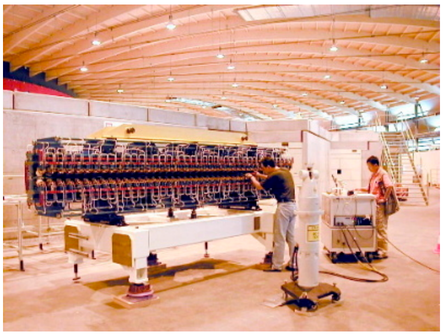

Fig.11: Pre-alignment of Insertion Device MS (UE212)

Most components of the beam lines have several reference holes. They can be used for positioning the components with respect to the network. Final alignment is realised by the synchrotron radiation beam itself.

Most of the beam lines are locate in beam line hutches. Additional local alignment network in each separate hutch is needed. Several floor and wall references have to be added and measured after engineering designs of the beam lines come out. Elevations of several floor areas were mapped by laser tracker LTD500. All the axes and the positions of the supports of the beam lines were well marked on the floor.

Each component has to be pre-aligned before installation into its working positions in a test area. Because most of the beam line components are installed in very limited locations. During pre-alignment some critical shapes and dimensions of the components have to be checked. The instruments such as laser tracker LTD500, precision level N3, theodolite TDA5005, TM5100A and Projector H360 were used for alignment and calibration of those

Fig.12: Alignment of the PX beam line

components frequently.

The SLS survey and alignment group has successfully positioned all components of the four beam lines to their final positions with high accuracy. The photon beams were guided through the optics until to the end stations within short time for all beam lines currently in operation.

The positions of the beam line components were not needed to be readjusted during commissioning and operation in last two years.

6. INSTRUMENTS

Our main instruments are the followings:
•Laser Tracker LTD500
•Precision Level Wild N3
•Theodolite TDA5005
•Theodolite TM5100A
•Projector ST360H

The Laser Tracker LTD 500 and Axyz software is our master tool. Operators have been well self-trained with Axyz software. A real 3D measurement was applied for tunnel network and positioning of the components. In our case the advantage of this approach is the following:

- high accuracy,
- high efficiency by a factor of 2 or 3,
- high reliability,
- free station and less space needed,
- less dependence on man operation skill,
- low total cost

The disadvantage is a slightly lower accuracy of the network roll angle in the narrow tunnel.

7. STUDY OF DYNAMIC ALIGNMENT OF THE STORAGE RING

In order to provide synchrotron radiation of highest quality under extremely stable and reproducible conditions, at the SLS storage ring several additional systems are under studying apart from conventional survey and alignment methods. They are shown in Figure 13, 14 and 15.

Monitoring of vertical as well as horizontal position changes of the girders and BPM stations is provided by three independent measurement systems: a hydrostatic levelling system (HLS), a horizontal positioning system (HPS) and a BPM position monitoring system (POMS). Each girder is equipped with 4 pick-ups of a hydrostatic levelling system (HLS). The horizontal position measurement

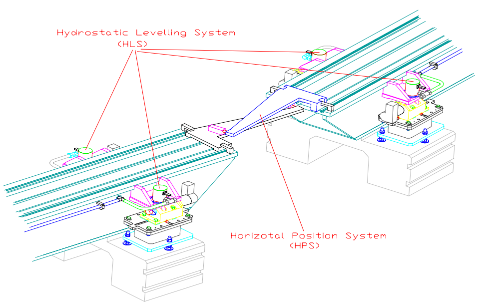

Fig. 13: The SR Dynamic Alignment Systems

system (HPS) is located between two adjacent girders under each dipole magnet. There are 72 BPMs in the storage ring.

All the zero points of the position monitors can be set after the girders are aligned by the conventional survey and alignment method to their final positions. Repositioning of the storage ring girders is possible through a girder mover system, which provides 2 µm resolution within an operating window of ± 2.5 mm.

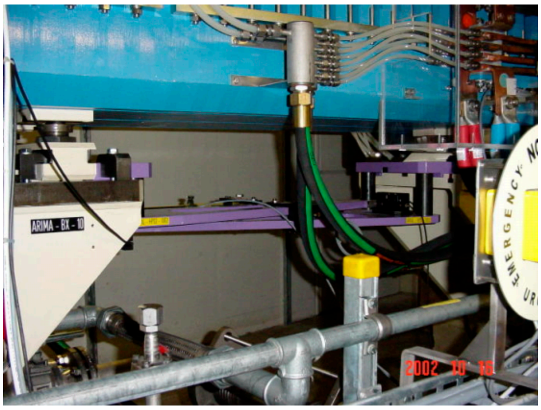

Fig. 14: The Horizontal Position System (HPS)

It is therefore possible to apply a SVD (single value decomposition) based dynamic alignment procedure [7], which allows to correct long-term drifts of storage ring components mechanically. In this case, HLS and HPS are used to determine misalignments and the girder movers act as correctors. Consequently, it is possible to reduce the average strength of the SLS storage ring corrector magnets, which are then again fully available for electron beam orbit corrections within feedback loops.

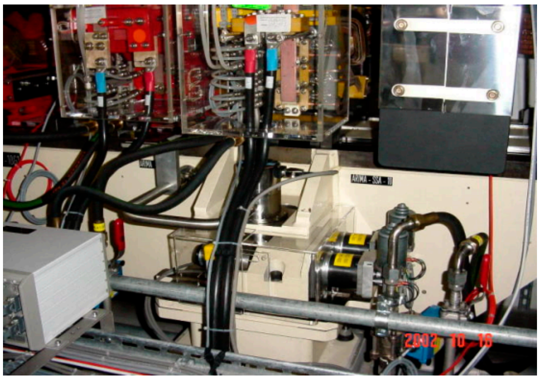

Fig. 15: The Hydrostatic Levelling System and Mover

The experience gained so far on the Hydrostatic Levelling System shows that micrometric range accuracies are indeed achievable. However, the long-term behaviour of the HLS system is characterised by significant drifts [8]. Several trials are under way in order to tackle this problem.

8. REFERENCES

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