EXPERIENCES WITH THE HYDROSTATIC LEVELLING SYSTEM AT THE SLS

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Abstract

The Hydrostatic Levelling System (HLS) of the SLS was installed and commissioned during year 2000. It is a measurement system for monitoring the vertical positions of the SLS storage ring girders. It is integrated in the concept of dynamic alignment. The HLS was modified and re-calibrated in 2002. Since January 2003 the system has collected approximately 2 million measurements. The analysis of the data shows that the displacements of the SLS storage ring foundation and of the girder supports were in the range of 0.15 mm in 2003.[1] The long term HLS stability was significantly improved. The short term precision of the HLS is in the micrometer range. The experience gained with the HLS is presented.

INTRODUCTION

The Hydrostatic Levelling System (HLS) of the SLS (Swiss Light Source) has been designed to monitor the vertical position as well as the pitch and yaw of the magnet girders of the SLS storage ring with a circumference of 288 meters. The HLS System of the SLS consists of a total of 192 level sensor pots mounted on the 48 girders, 4 ports on each girder (see Figs. 1 and 2). It is integrated with the horizotal position measurement system in the concept of dynamic alignment. The 100-mm diameter cylindrical stainless steel pots are connected by a half filled stainless steel pipe with an inner diameter of 21 mm. The non-contact measurement principle avoids corrosion due to moistening and wetting of the contact points. The temperature of the sensor is a few degrees higher than the water temperature.

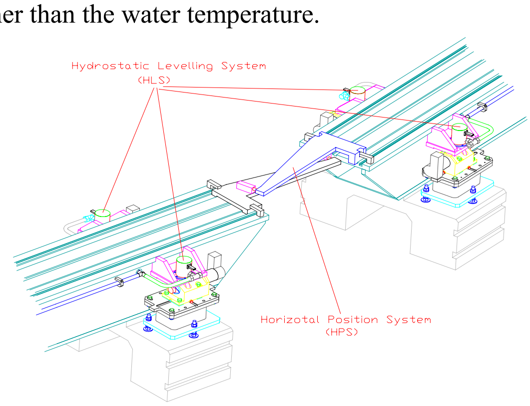

Figure 1: Layout of the HLS

Figure 2: HLS and its filling station.

CALIBRATION OF THE HLS

The HLS was calibrated during the year 2000 by the manufacturer, Edi Meier + Partner AG. The analogue output of the level sensor is a non linear voltage signal (Figure 3) with different curvature for each level sensor.

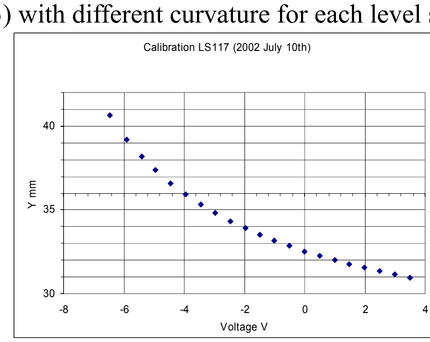

Figure 3: Calibration curvature

The measured voltages of the level sensors are transformed into position values by the following relation:

$$Y^n[mm] = a_n V_n^{\ 2} + b_n V_n + C_n \qquad (1)$$

DATA RECORDING AND HISTORY

The HLS collected several millions of voltage data since 2001. As an example, Figure 4 shows the voltage data of the 2nd HLS sensor of girder 1 in section 7 from January 2001 to June 2004.

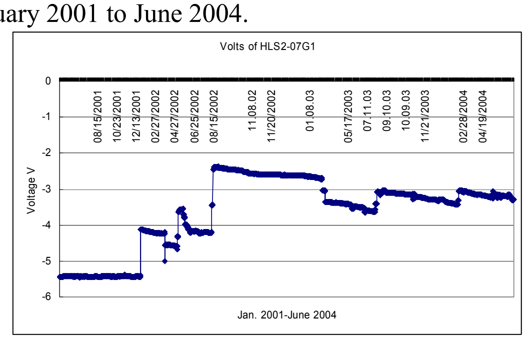

Figure 4: Voltage of the 2nd HLS sensor of girder 1 in section 7 from Jan. 2001 to June 2004

The vertical position can be calculated from the registered voltages as shows in Figure 5.

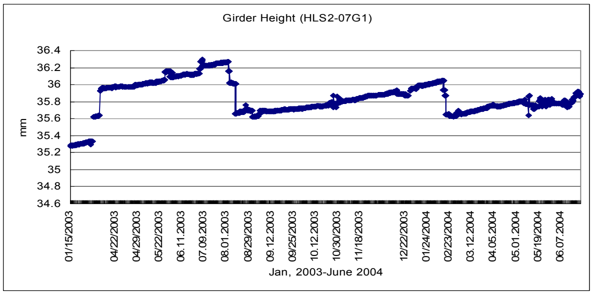

Figure 5: Vertical position of the 2nd HLS sensor of girder 1 in section 7 from Jan. 2001 to June 2004

During the first period after HLS installation, in order to get high accuracy of the HLS sensor, the water level was kept as close as possible to the sensor surface The ripples of about 20 µm (over 2.5 months) of the pot readings have been observed by about half of the HLS sensors. At that time it was assumed that the total water quantity in the HLS system should stay stable for a long period, based on the assumption that the air humidity inside the HLS tube should reach 100 percents after a short time. In this case the mean water level in HLS system could come to equilibrium in the absence of a big leakage shortly after sealing the HLS system. It was assumed that the changes of the voltages were indicating the real movements of the HLS supports.

"Despite of the good results obtained initially, after a period of months, roughly half of the pots remained stable while the other half started drifting again" [2]. The drift rate in the first 25 days was negligible while the drift rate in the following 40 days suddenly became 20 µm per day. Then in the following 80 days the drift rate was almost stable at 2 µm per day (see Fig. 6). It was also remarkable that all of the drifting pots were drifting in the same direction.

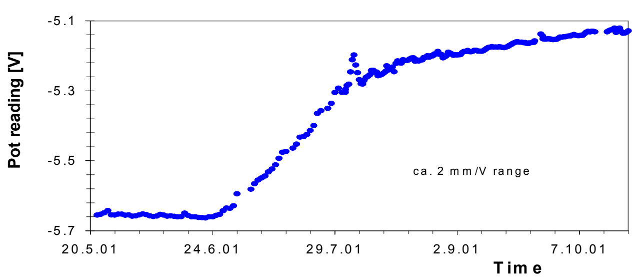

Figure 6: HLS sensor reading from May to Oct. 2001

During the second period starting in 2002 several attempts were made to stop the drifts, such as adding an O-ring, changing geometry and water composition. All the pots were re-calibrated with respect to their working point in Aug. 2002. From this time on the water level was kept roughly 1mm higher than the mid plane of the tube. Figure 5 indicates that a drift rate of the water level of about 2-4 micros per day have been measured at all HLS sensors up to now. Similar drift rate about of 2 µm per day can be observed in the ESRF HLS System.

A NEW METHOD OF DATA ANALYSIS

The voltages of each sensor were recorded and converted into vertical positions using formula (1). They are called raw data. A new method of the HLS data analysis, based on the drift evidence was then applied to the raw data.

The assumption is that these drifts consist of the following contributions:

* Drift due to evaporation
* Drift due to different heat expansion coefficients between the pipe and the working fluid during the temperature variation
* Real displacements of the HLS pots
* Stability of the sensors
* Errors of sensor calibration
* Other gross errors due to known and unknown effects
* Steep drifts caused by filling and purging water

In order to exclude shifts due to evaporation, re-filling and different heat expansion coefficients between the pipe and working fluid, the relative height of the 192 sensor values is subtracted from the raw data using the following formula:

$$Y_{AVG} = \sum_{1}^{n} Y[mm]/n \qquad (2)$$

$$Y^{n}{}_{\mathrm{Re}\,lative} = Y^{n}[mm] - Y_{AVG} \qquad (3)$$

n=P+((S-1)*4+G)*4
n: Sensor Number, Value :1-192
P: Pot number, Value: 1-4
S: Section number of the SR, Value: 1-12
G: Girder number in each Section, Value: 1-4

RESULT IN THE LONG TERM

Figure 7 shows the vertical relative positions of the four girders N.33, N.34, N35 and N36 in sector nine during the year 2003. The peak to peak deviation during 2003 is less then 0.3 mm.

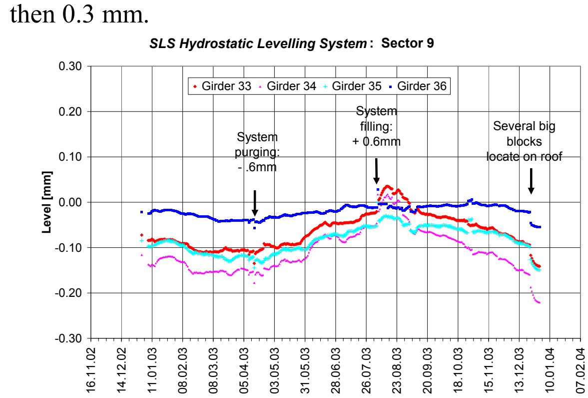

Figure 7: The vertical relative positions of the 4 HLS pots of the girders of the sector 9 from January to August 2003

Because of the exceptionally hot weather in August 2003, the air conditioning system in the SLS reached its limits and the temperature inside the tunnel of the storage ring increased by about 4 degrees. Girders N.33, N.34 and N.35 are located on top of the media channel with water pipes and cable trays. Consequently the sharpest curves of displacement appear for these elements during the hot period. At the end of December 2003 the roof of the SLS storage ring tunnel in sectors 4 and 5 was opened. Several concrete blocks of about 10 tons each, were temporarily stored on the nearby parts of the tunnel roof. This major operation in 2003 is documented, so the levels of the HLS experienced significant changes. It is still difficult to explain exactly all of the curvatures but the results from this data analysis are believable.

Figure 8 shows the mean deviations of all girders at the beginning, in the middle and at the end of year 2003. The deviations of the girders were extracted using the calibration constants from August 2002. It is clear that the peak-to-peak deviations of 48 girders of the SLS storage ring were less than 0.3 mm from August 2002 to the end of year 2003. The biggest deviation appeared at the girder 34 which is located exactly on the top of the media tunnel with water pipes. These deviations were oscillating from summer to winter.

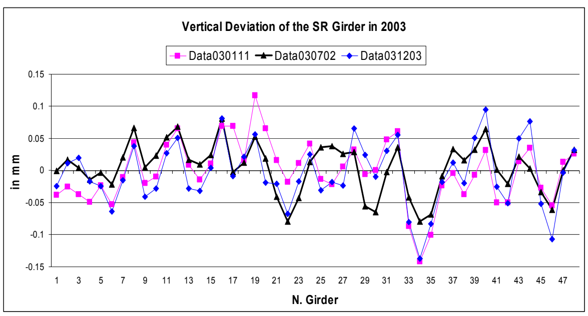

Figure 8: Mean deviations of all girders at the beginning, in the middle and at the end of year 2003.

The curve of girder deviations in figure 9 was extracted by using the calibration constants from the beginning of year 2001. Again, it is clear that the peak-to-peak deviations of 48 girders of the SLS storage ring were less than 1.6 mm from August 2000 to Jane 2003. Another curve of girder deviations was extracted by using the calibration constants from April 2003. This one reveals only 0.1 mm deviation during the period of a year. It shows clearly that the stability of the foundation and supports of the SLS Storage ring is very high.

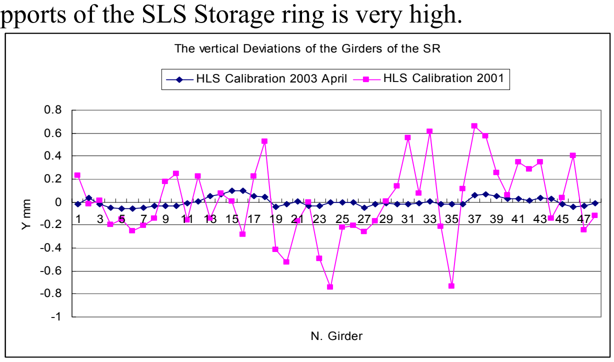

Figure 9: Vertical deviations of the SR Girder positions in June 2004

SHORT TERM RESULTS

Oscillations of the SLS HLS with small amplitudes between 1 µm and 5 µm have been observed in 2003. The temporal wavelength of the oscillations was found to be on the order of 12 hours.

Further investigations showed that the oscillations can be correlated to tidal forces. In case of an eclipse the influence of sun and moon is known to be particularly high because sun, earth and moon are aligned and the superimposed gravity forces lead to stronger motion than usual.

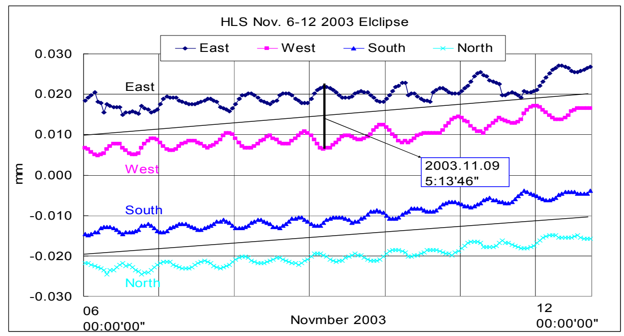

Figure 10: Oscillations of the SLS HLS

Figure 10 shows the level of 4 pots during the period of the lunar eclipse on November 9, 2003. It can be clearly seen that the level difference in the SLS HLS becomes a maximum at the time of the lunar eclipse. It can be also clearly observed that the level differences between east and west are larger than the level differences between north and south of the storage ring.

The precision of SLS HLS is, however, on the order of a micrometer over the period of a few days.

CONCLUSION

The 3-years experience with the Hydrostatic Levelling System of the SLS reveals not only a long term stability of the HLS System but a very stable storage ring foundation as well. The high HLS precision over short time periods allows the observation of tides, induced by the gravity forces of the sun and the moon.

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