Precise Long Term Deformations: Results of the Hydrostatic Levelling System at the "Swiss Light Source" Synchrotron

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SUMMARY

A Hydrostatic Levelling System (HLS) is a tool for measuring vertical displacements of large machines or buildings. The Hydrostatic Levelling System at the Swiss Light Source (SLS) of the Paul Scherrer Institute (PSI), Switzerland, shows reliable long term stability over the past years. The high resolution of the HLS allows the observation of ground deformations induced by tidal forces. As a special feature, each level sensor is equipped with a touching point which allows a remote recalibration of the system. In this presentation, the latest results are discussed and an overview of the HLS design at the SLS is given. In addition, the new PWR (Precision Wide Range)-HLS, a more compact OEM – level sensor version, is introduced.

ZUSAMMENFASSUNG

Ein “Hydrostatisches Levelling System” (HLS) ist ein Instrument zur präzisen Erfassung vertikaler Verschiebungen von grossen Maschinen oder Gebäuden. Das Hydrostatische Levelling System im Swiss Light Source Synchrotron (SLS) des Paul Scherrer Instituts (PSI, Schweiz) zeigt eine zuverlässige Langzeitstabilität über die letzten Jahre. Die hohe Auflösung des HLS erlaubt die Beobachtung von Bodendeformationen verursacht durch Erdgezeiten. Als spezielle Funktion der HLS Sensoren ist der “Berührungspunkt” zu nennen, welcher eine ferngesteuerte Rekalibrierung des Systems ermöglicht. In dieser Präsentation werden die neuesten Resultate diskutiert sowie ein Überblick über die Ausführung des HLS im SLS gegeben. Zusätzlich wird das neue Präzisionsbreitband-HLS vorgestellt, eine kompaktere OEM – Höhensensorversion.

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1. INTRODUCTION

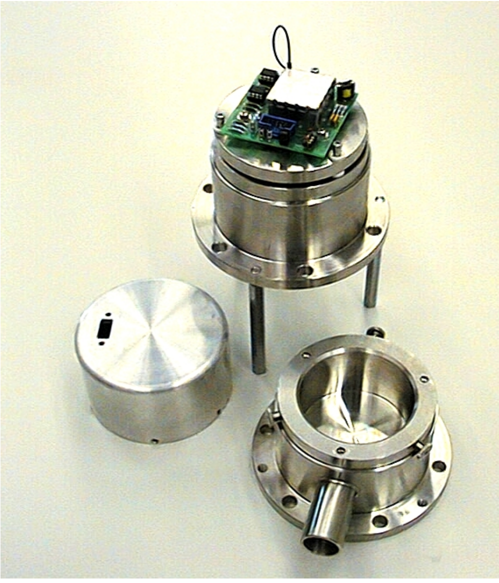
The Hydrostatic Levelling System (HLS) is a tool for measuring vertical displacements. The advantages of hydrostatic measuring systems is their high accuracy and resolution. With regard to this aspect, these systems are far superior to modern geodetic instruments such as tachymeter and digital levelling devices. Due to their simple and robust configuration, hydrostatic measuring systems are furthermore well suited for permanent, all-season monitoring, combined with remote control systems and automated data acquisition.

Hydrostatic measuring systems work all on the fundamental principle which says that a water surface which is under the influence of a gravitational field and free to move, orients towards a certain level surface. Measuring pots, which are connected to each other obey the law of the communicating vessels and therefore the water surface represents a stable, reliable and very accurate reference for levelling purposes. The fundamental layouts and the calculation of hydrostatic measuring systems have been decribed 1998 at the XXI Congress of the International Federation of Surveyors in Brighton [1]. In the present paper we focus on the “half filled pipe- type” which is the most reliable system layout when best longterm stability and temperature independence are required.

2. THE HYDROSTATIC LEVELLING SYSTEM (HLS)

2.1 Technical Background

The HLS consists of level sensors (LS), linked together with stainless steel pipes, half filled with liquid. The lower part of the LS is electrically isolated from the upper part, carrying the electrode and the electronic equipment (Fig. 1). In order to measure the fluid level of each LS, the liquid level has to be determined. The fill level is determined capacitively, where the fluid surface and the electrode act each as a capacitor plate (Fig. 2). In order to avoid condensation water at the electrode, the LS has an integrated heating device. In the case of fluid touching the electrode, a specially designed ring ensures a quick and complete run off.



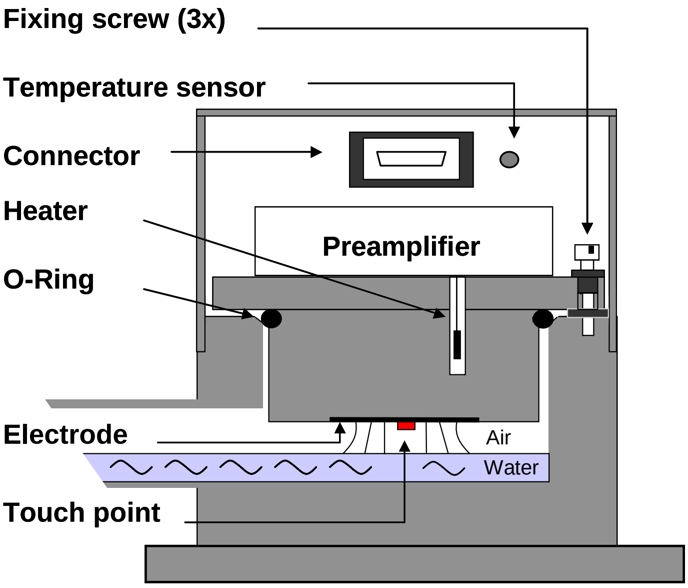


Fig. 1: Building blocks of the HLS.

Fig. 2: Cross section of a HLS level sensor.

As a special feature, each LS is equipped with a touch point. The touch point is located near the electrode. This allows a calibration of the zero-level at any time during the HLS operation within the demanded accuracy. The calibration is done by raising the fluid level slowly until the touch point is reached [2]. The detection of the touch point is shown in Figure 3.

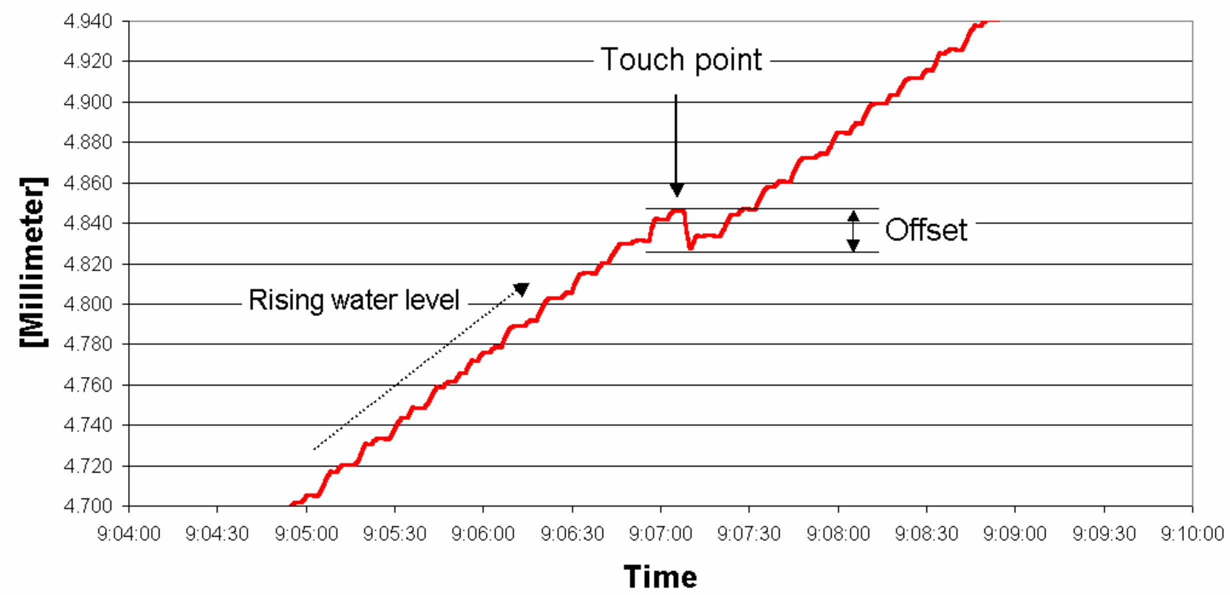


Fig. 3: Detection of the touch point during the filling process. For every level sensor this point is well defined. The slope of the signal is constant. After the touch point has been reached, a constant offset from the true level signal is subtracted. In this way, by the use of just one data channel the following information can be retrieved: “the current fluid level” and “the touch point has been reached”.

The analogue data from the sensors is being converted by an A/D converter into digital signals. The mode of data transfer is dependent on the actual application. In the case of integral systems such as the HLS at the PSI, a CAN-OPEN bus has been applied. Considering the large number of LS and data to be transferred, the CAN-OPEN bus is superior to alternative solutions such as the RS-485 bus.

2.2 The HLS at the Swiss Light Source (SLS)

The HLS installed at the SLS was designed to meet the following specifications: measuring range 14 mm, resolution 2 µm, accuracy better than 10 µm. The storage ring of the synchrotron is subdivided into 12 sectors, each containing four girders on which the focussing electromagnets are mounted. Every girder is monitored by four installed level sensors (LS) (Figure 4 and 5). This leads to a total amount of 192 LS, which are linked together by half full steel pipes.

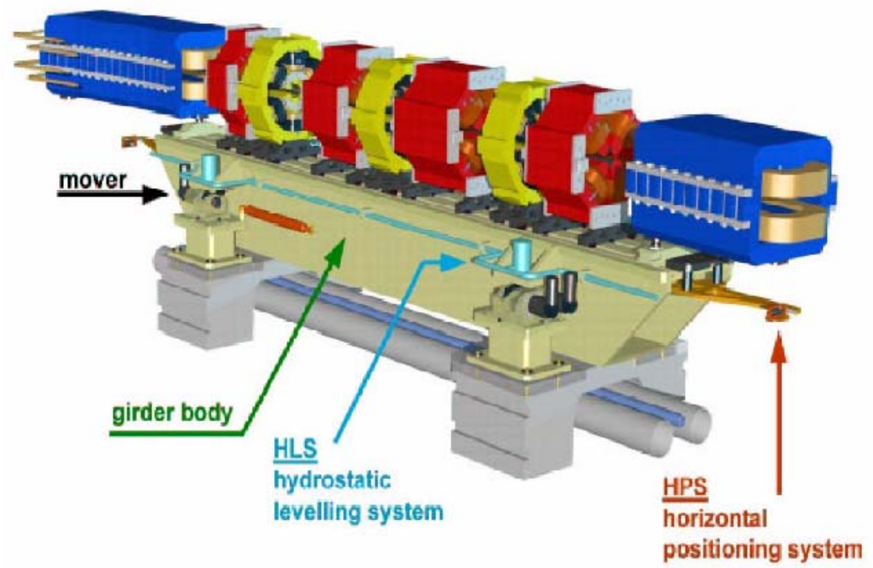


Fig. 4: Girder body carrying the electromagnets. The movers are intentioned to move the whole girder in order to re-adjust the electromagnets. The girder movement is monitored by the HLS.

Fig. 5: Level sensor (LS) mounted on the girder. Below it an eccentric cam disc is visible.

After a couple of months, it is necessary to compensate the fluid level for natural evaporation. At the SLS, the HLS can be refilled (or emptied) entirely by remote control over the internet (Fig. 6 and 7). In order to refill the HLS, a filling tank is located inside the storage ring tunnel (Fig. 8). If this tank has a low fluid level, it can be refilled through another tank which is located outside the storage ring and connected by a pipe and a fluid pump. Thus, no interruption of the SLS operation is needed in order to control or recalibrate the HLS.

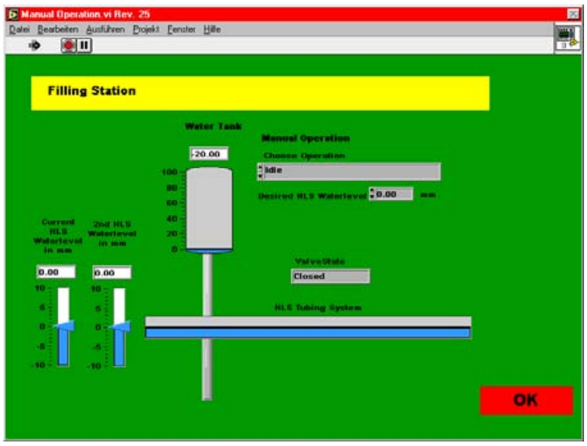


Fig. 6: Graphical interface for the automatic refilling station.

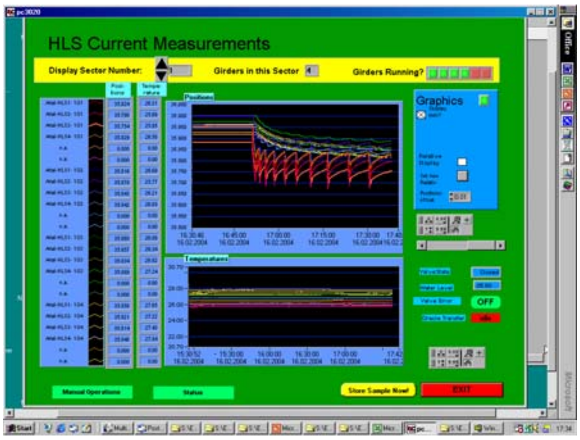


Fig. 7: Graphical interface, showing data of the refilling process.

Fig. 8: Inner filling station. The two red pumps for draining (left) and refilling (right) of the HLS can be completely remote controlled. The inner filling station is directly connected to the half-filled HLS pipes which can be seen at the lower left corner of this figure.

The HLS at the SLS showed reliable and stable signals over the past years [3]. Events such as the temporary displacement of shielding elements on the roof (Fig. 9) are visible. The earth tides and their geographical orientation can be clearly identified (Fig10).

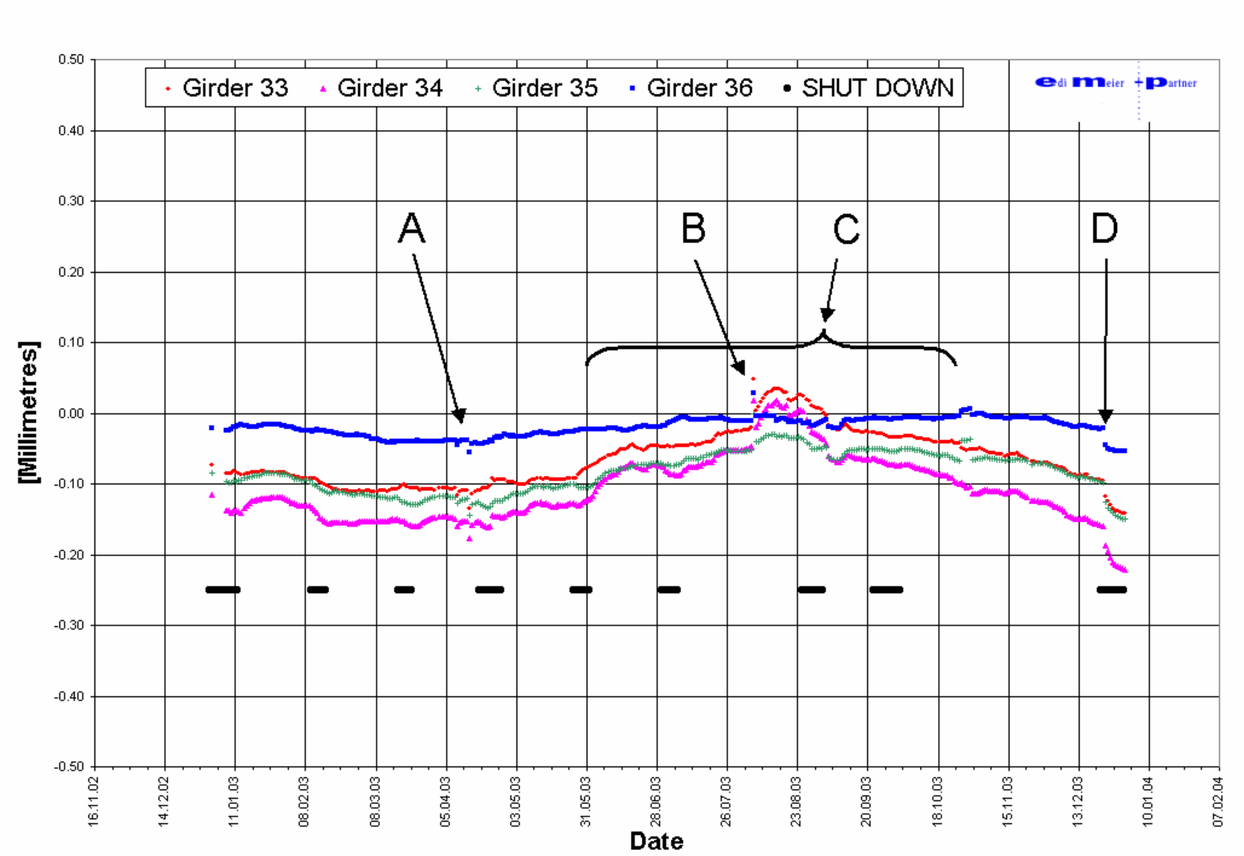


Fig. 9: Long-term monitoring in sector 9 (4 girders) of the PSI-SLS. Clearly visible are a system purging (A) and filling (B). The exceptional hot summer of 2003 made it necessary to raise the operating temperature by several degrees. While the girders 33 – 35 show a significant reaction to this change in temperature (C), girder no. 36 stays almost steady. The reason are the cooling pipes for the SLS which are located near that girder, causing a lower temperature at this particular spot. During the shutdown in December 2003 (D) several heavy shielding elements have been placed temporary on the roof of sector 9. That event caused vertical displacements in this sector.

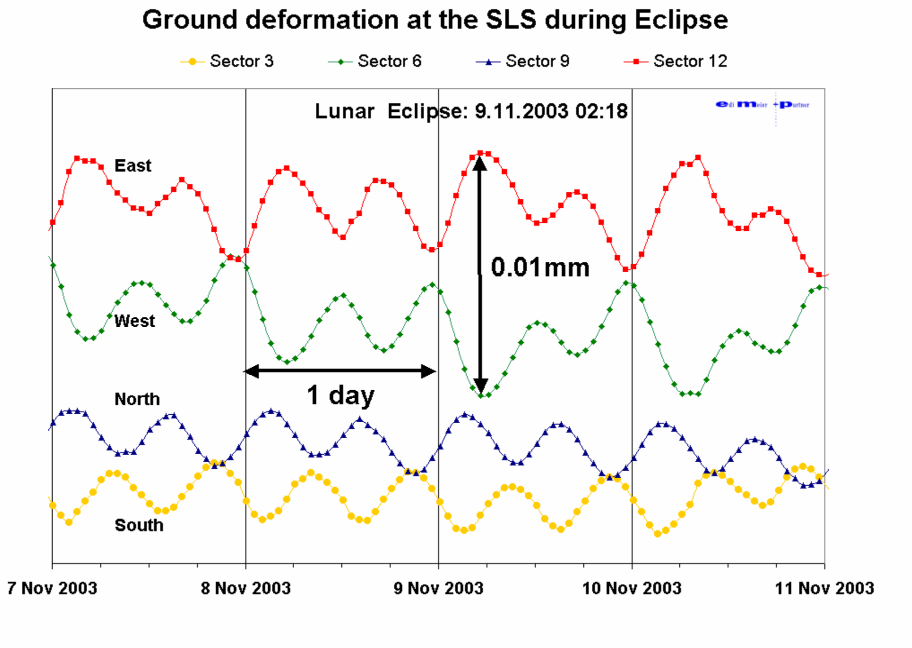


Figure 10: A four day period of the year 2003 with a time resolution of 1 hour. The influence of the earth tides with 2 periods a day is clearly visible. Note the high amplitude difference between east and west during the eclipse of the moon.

2.3 The Precision Wide Range HLS (PWR-HLS)

As a further development of the HLS, the Precision Wide Range (PWR) HLS has been created (Fig. 11). The PWR-HLS, originally developed for the dynamically monitoring of road bridges, can be used in many applications. While the measuring system itself stays unchanged, a few adjustments have been made. The measuring pots are connected among each other by 54 mm (instead of 25 mm) standard pipes, allowing a wider measuring range and a faster response time to changes of the water level. The signal is measured directly as an analogue DC voltage. The PWR-HLS can be seen as a OEM level sensor version, which can be adapted to the particular application.

Fig. 11: Precision Wide Range (PWR) HLS with wider opening.

3. CONCLUSIONS AND OUTLOOK

During the past the HLS has proven its fitness for long-term operation. Draining and refilling of the measuring fluid do not demand an interruption of the measuring process. Due to the dense instrumentation (192 level sensors), an extensive analysis of the events causing a change in fluid level is possible. Thus, events such as electrical disturbances, fluid movements and real deformation signals can be distinguished. The very good experience made at the SLS show that the HLS is a suitable alignment tool. Its field of application ranges from simple layouts with just two level sensors up to the monitoring of large systems such as the SLS or even larger installations. More research on the fluid dynamics inside large pipe systems would be desirable. A combination of the HLS with other alignment tools such as continuous inclinometers would lead to more interesting cognitions.

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BIOGRAPHICAL NOTES

Edi Meier, is managing director of the engineering company Edi Meier + Partner AG, Winterthur, Switzerland. He studied Geophysics at the Swiss Federal Institute of Technology, ETH Zurich. Subsequently he worked as a manufacturer of seismic instruments (Streckeisen Switzerland)during six years and founded 1987 his own engineering company. Since 1995 the company is collaborating in research and development of new instruments with the Insitute of Geodesy and Photgrammetry, ETH Zurich.

Hilmar Ingensand is a full professor at the ETH Zurich since 1993, holding the Chair of Geodetic Metrology and Engineering Geodesy at the Institute of Geodesy and Photogrammetry. His main research activities at the ETHZ are geodetic metrology, sensor technology and engineering geodesy. He is the author or co-author of 170 publications, respectively. He studied geodesy at the University of Bonn and, in 1984, received a Ph.D. for his thesis on "Development of Electronic Inclinometers" at the Institute of Geodesy, Bonn. Before his professorship, he worked several years as a development engineer at Leica AG, Switzerland, and then as head of the "Basic Research and Applications" group.

Fuqiang Wei is a mechanical engineer at Paul Scherrer Institut in Switzerland. He has successfully worked more than 20 years as responsor of survey and alignment for accelerators at several institutes in China, Italy and Switzerland.

Leonid Rivkin is ordinary professor at the Swiss Federal Institute of Technology Lausanne, EPFL (Particle Accelerator Physics Laboratory). He is the head of the department “Large Research Facilities” of the Paul Scherrer Institute. He was one of the responsible people for planning and building the “Swiss Light Source Synchrotron” SLS.

Alexander Somieski is an engineer of Edi Meier + Partner AG at Winterthur in Switzerland. During his PhD study at ETH Zurich he was involved in several international research projects in the area of surveying and satellite geodesy. Since 2005, he develops software for measurement control and automatization in the field of geodesy, geophysics and civil engineering. In addition, he is responsible for engineering projects deeling with vibration measurements and deformation monitoring by means of seismometers and hydrostatic levelling systems, respectively.

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