STABILITY ASPECTS AND TOP-UP

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Since September 2001 the SLS is operating in the mode of frequent injection ("top-up") in order to stabilize the beam current to below the % level. Apart from the practically "infinite" beam lifetime at all beam currents the main advantage of this operation mode consists in the fact that all storage ring components reach a thermal equilibrium state. As a result especially the drifts of the vacuum chamber with respect to the girder mounted magnets turn out to be negligible. Since the BPMs define the reference for the slow orbit feedback the achieved excellent mechanical stability significantly improves the medium and long term orbit stability.

INTRODUCTION

It is vital for a successful user operation to reproduce and stabilize a previously established reference orbit ("golden orbit") within 1/10th of the vertical beam size corresponding to $\approx 1\ \mu$m at the location of the insertion devices (IDs). This is accomplished by a slow orbit feedback which constrains the RMS values of the difference orbit to $\approx 1\ \mu$m. Current stabilization through "top-up" operation ensures that the BPM reference used by the feedback does not change with respect to the magnetic elements of the storage ring and the beam-line components.

SLOW ORBIT FEEDBACK

Global closed orbit correction in the SLS storage ring is based on the **S**ingular **V**alue **D**ecomposition (SVD) technique. For the horizontal orbit correction it is crucial to take into account path-length effects by correcting off-energy orbits by means of the RF frequency. The difference of the original orbit and the SVD fitted off-energy part, with a deviation of dp/p corresponding to a frequency change Δf, is submitted to the orbit correction.
Since the beginning of the commissioning of the SLS storage ring, this scheme has been successfully applied to perform operator induced corrections. Due to the modularity of the beam dynamics software environment [1], thoroughly tested software components could be reused to implement a **S**low **O**rbit **F**eed**B**ack (SOFB) [2] presently running at correction frequencies of $<$ 1 Hz. The quiet noise environment of the SLS storage ring allows orbit oscillations of $>$ 1 Hz to remain uncorrected [3].

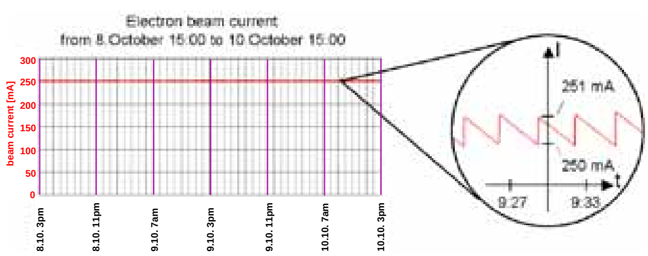

Fig. 1: Typical "top-up" run over 2 days at a current threshold of 250 mA with a deadband of 1 mA in October 2002. At a lifetime of τ = 12 h the time between injections is 3 min corresponding to 960 injections in the depicted time period.

TOP-UP OPERATION

One of the most desired features of modern synchrotron light sources is the option for a frequent injection ("top-up") operation mode. It requires the ability to inject beam with closed ID gaps and with experiments at the various beam-lines being online. At the SLS "top-up" is the standard mode of operation since September 2001 [4, 5]. Fig. 1 depicts a typical "top-up" run in October 2002 allowing for current variation within a range of 250 - 251 mA. Apart from the practically "infinite" beam lifetime at all beam currents the main advantage of this operation mode consists in the fact that all storage ring components reach a thermal equilibrium state. As a result especially the drifts of the vacuum chamber with respect to the girder mounted magnets turn out to be negligible. This has been verified utilizing the **PO**sition **M**onitoring **S**ystem (POMS) [6] which allows to measure the BPM (chamber) positions with respect to the adjacent quadrupoles [6]. Fig. 2 shows the change of the horizontal offset of **ARIDI-BPM-02SE** in ring sector 2 with respect to its adjacent quadrupole **ARIMA-QSD-02** in the case of beam accumulation, "top-up" and decaying beam operation. No movement within the 0.5 μm resolution of the POMS readout is observed during the 9 h "top-up" run which implies that the BPM is not moving with respect to the adjacent quadrupole. Since the BPMs define the reference for the SOFB this

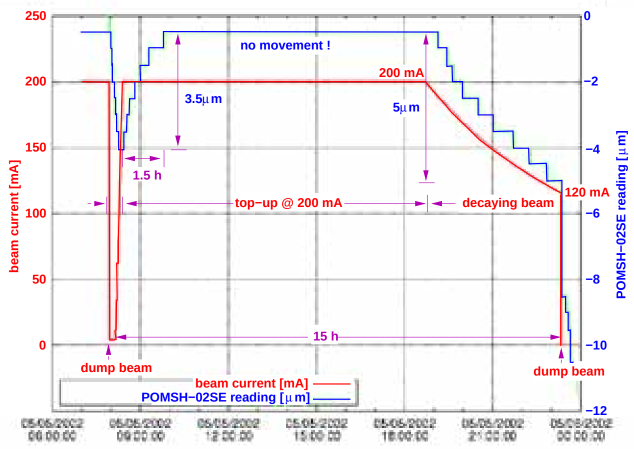

Fig. 2: Change of the horizontal offset of **ARIDI-BPM-02SE** in ring sector 2 with respect to its adjacent quadrupole **ARIMA-QSD-02** in the case of beam accumulation, "top-up" and decaying beam operation.

excellent mechanical stability improves significantly the medium and long term orbit stability. Moreover, the BPMs show no beam current dependence since the current changes are sufficiently small and the experiments experience a constant heat load on their beamline components.

MEDIUM TERM STABILITY

The results of a typical user run between August, 13-16 2002 are shown. During this run the storage ring was operated in “top-up” mode where the electron current was kept constant at 180 mA within a band of 0.5 mA. The SOFB has stabilized the orbit to RMS values of $\approx 1\ \mu$m with respect to the reference orbit (“golden orbit”) in both planes (see Fig. 3). The RF fre-

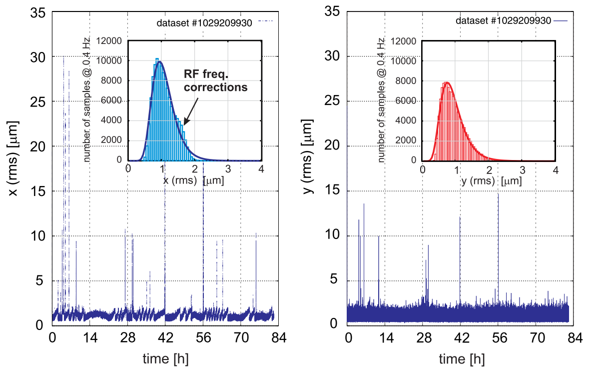

Fig. 3: RMS values of horizontal (left) and vertical (right) position readings at all 72 BPMs together with the corresponding histograms.

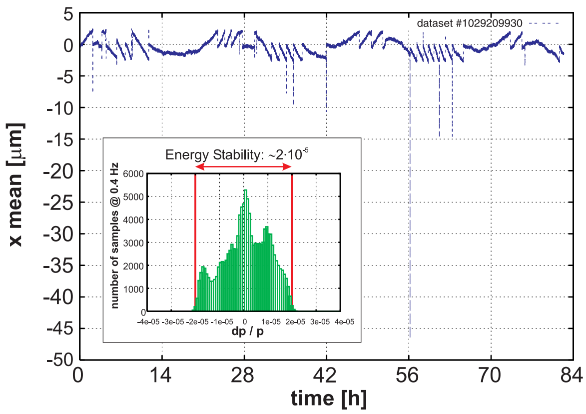

Fig. 4: Mean value of the horizontal orbit with respect to the “golden orbit” during a 3 days “top-up” run at 180 mA. The proposed frequency correction Δf is applied whenever a threshold of 5 Hz is passed corresponding to an energy deviation dp/p $\approx$ 2·10^{-5}.

quency is corrected by Δf whenever $|\Delta f|$ exceeds 5 Hz corresponding to an energy change of dp/p $\approx 2 \cdot 10^{-5}$. In this particular case a frequency correction is performed every $\approx$ 45 min. Consequently the horizontal RMS value increases (see “saw tooth” in Fig. 4) while Δf is not applied. A frequency change by 5 Hz corresponds to a path length change of 3 μm for a 288 m

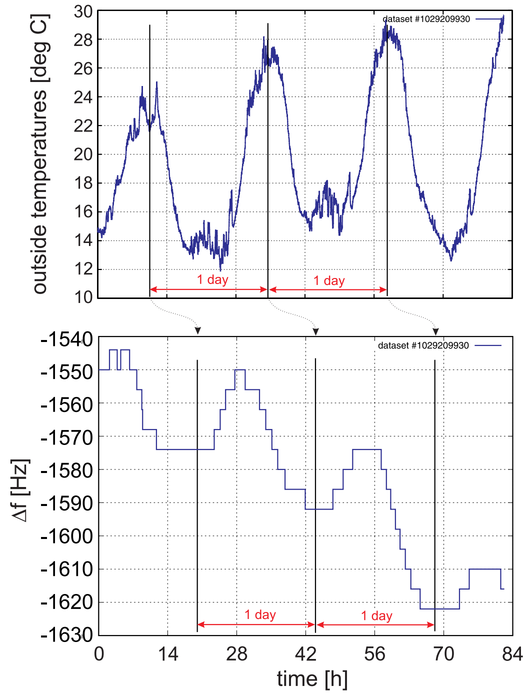

Fig. 5: Correlation between the outside air temperature and RF frequency changes during the 3 day user run. With some thermal delay temperature maxima correspond to frequency minima.

circumference of the storage ring and an RF frequency of 500 MHz. Although the tunnel temperature is regulated within $\pm 1^\circ$C the daily outside air temperature variations have an influence on the building and hence on the circumference of the storage ring. This cycle and the corresponding frequency corrections can clearly be observed in Fig. 5.

In the middle of August 2002 the first four-blade X-BPM [7] at SLS was commissioned at the protein crystallography beam-line (ID **U24**). A data set taken during a two days run on August, 10-11, shows daily photon beam position drifts of 2.3 μm and 1.7 μm horizontally and vertically (Fig. 6). Their source could not yet be

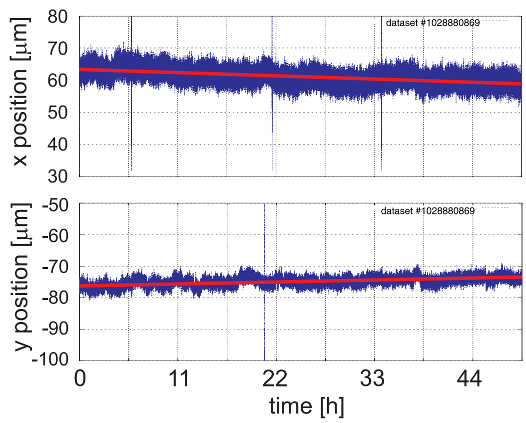

Fig. 6: Horizontal and vertical photon beam position at the first X-BPM at the protein crystallography beamline. The straight lines indicate a daily drift of 2.3 μm horizontally and 1.7 μm vertically.

identified and thus needs further investigation. However, the residual X-BPM RMS values of σ_x = 2.7 μm and σ_y = 1.5 μm are in good agreement with the estimated position and angle fluctuations at the ID calculated from the up- and downstream BPMs when considering the lever arm of $\approx$ 9 m from the radiation source point to the X-BPM and the beta functions at the corresponding locations.
The variation of the orbit positions at the BPMs adjacent to ID **U24** over 3 days of "top-up" operation yields Gaussian distributions with σ_x = 1.0 μm and σ_y = 0.7 μm for both upstream and downstream BPMs. Those fluctuations translate into an angular stability of σ_Θ(horizontal) = 0.3 μrad and σ_Θ(vertical) = 0.2 μrad at the ID.

LONG TERM STABILITY

Fig. 7 depicts the variation of RMS difference orbit values over 28 weeks of machine operation interrupted by five previously scheduled shutdowns. ID gap changes

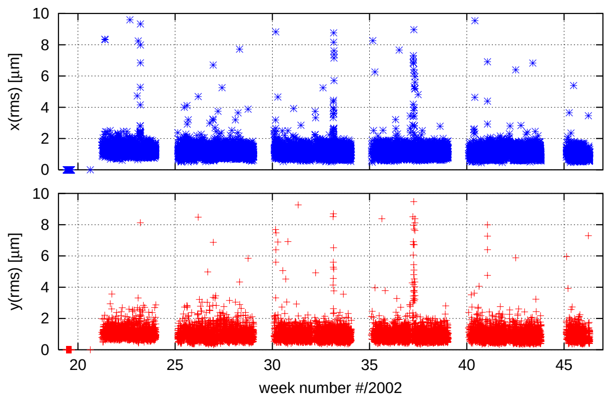

Fig. 7: Horizontal and Vertical RMS difference orbit values over 28 weeks of machine operation. Gaps without data indicate scheduled shutdowns.

and orbit fluctuations during beam accumulation account for the occasional orbit excursions larger than 2 - 3 μm.
Fig. 8 summarizes the changes of the storage ring circumference in 2002. The seasonal variations due to changes of the outside temperature are overlaid with a continuous drift which can be explained by the ongoing settlement of the concrete slab. In addition shutdowns introduce temporary fluctuations of the circumference. The observed overall variation of 1.2 mm corresponds to a frequency change of $\approx$ 2 kHz.

CONCLUSIONS

In 2002 a medium and long term orbit stability at the ID locations of $<$ 1 μm and an energy stability of dp/p $\approx$ 2 $\cdot 10^{-5}$ have been achieved (The result of a recent spin depolarization measurement carried out in January 2003 indicating an energy shift of -1 % since September 2002 [8] needs confirmation).
The "top-up" operation mode has proven to be a key ingredient for the excellent orbit stability in the SLS storage ring.

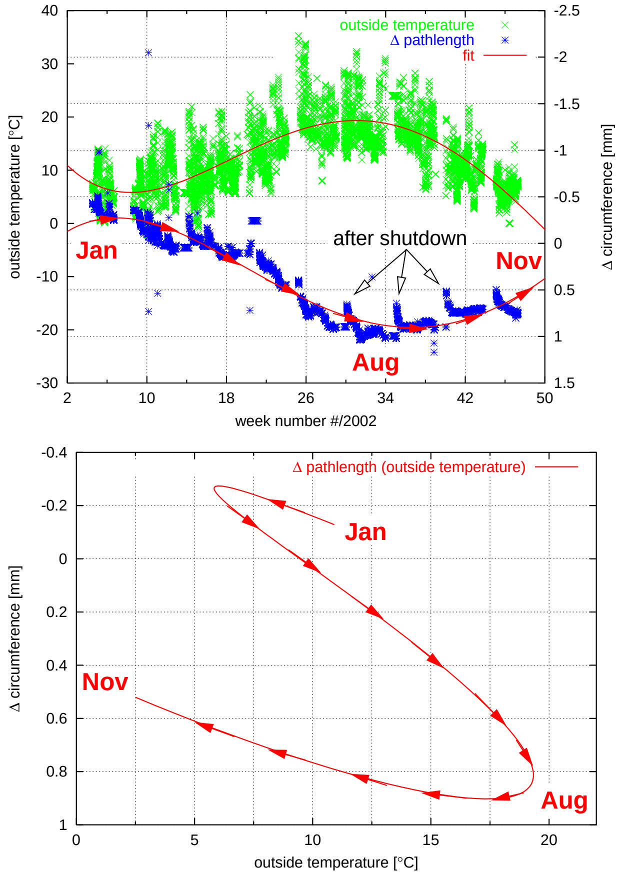

Fig. 8: Change of the storage ring circumference vs. outside air temperature over 48 weeks of machine operation in 2002. The observed pathlength variation of 1.2 mm corresponds to a frequency change of $\approx$ 2 KHz.

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