# TOP-UP OPERATION EXPERIENCE AT THE SWISS LIGHT SOURCE

A. Lüdeke, M. Muñoz, PSI, Switzerland

*Abstract*

The Swiss Light Source (SLS) is a medium energy $3^{rd}$ generation light source, optimized for mini-gap undulators. A touschek dominated beam life time of 3.5 *h* is expected for the design current of 400 *mA* in the presence of undulators with 4 *mm* full gap size. Therefore a continuous refilling of beam-current, the so called top-up operation, is a prerequisite for most user operation. This mode was used successfully already in early commissioning and has been the standard mode for user operation for the last year. The gained experience will be described in this paper.

## 1 INTRODUCTION

The use of frequent filling operation modes or "top-up" is one of the desired characteristics of modern synchrotron light sources. It requires the ability to re-inject electrons into the storage ring while synchrotron radiation experiments are taking data.

This ability makes it possible to lift the demands on beam lifetime: touschek lifetime limitation can be accepted and even further lifetime reductions by small gap insertion devices are acceptable.

During the design of the SLS it turned out that the requirements of the users regarding photon flux and bandwidth could only be met by low emittance high current beam and small gap in-vacuum undulators. The design values of 400 mA beam current and $4mm$ full width gap lead to an expected lifetime of 3.5 hours. It became clear that top-up is then indispensable for user operation at the SLS.

## 2 REQUIREMENTS FOR TOP-UP

Top-Up operation was already tested at different light sources [1], [2]. Several requirements have to been met for the successful implementation of top-up as the standard operation mode of a light source.

First of all the use of top-up has some implications on the design of the injector system [3]. Very reliable systems are needed since the injector has to provide beam continuously during the whole user run. The need to have the injector always available raises also the demands on it's stability, since a manual correction of drifts is nearly impossible with one shot per minute. The non-stop operation also increases the importance to minimize the power consumption of the injector system in order to reduce operation costs.

Another important topic is the injection itself. A very careful set-up of the injection and especially the closure of the injection bump is required, since the distortion of the stored beam directly effects the data acquisition of the experiments and any particle losses at injection can hit the optic of the beamline through the open beam-shutters. High reliability of the pulsers is needed to reach nearly 100 % injection efficiency. A low emittance of the injector helps also to reduce the losses of the injected particles in the storage ring. Additionally one needs adequate diagnostic to measure and monitor the losses and orbit distortions.

Top-up has also some effects on the design of user experiments. While the distortions of the injection can be minimized, they cannot be suppressed entirely. Therefore each experiment should foresee the possibility to gate out data acquisition for about one millisecond at each injection or to add a flag to the data recorded during injections. Gating signals must be provided for all experiments.

## 3 TOP-UP AT THE SLS

The first top-up operation at the SLS was done during the commissioning in June 2001 [4]. Two modes of top-up were tested at the SLS:

- **Top-Up:** Injections in fixed intervals, leaving out single injections if current is above a predefined beam current value.
- **Frequent Injections:** Define desired current band and start injections when the beam current drops below the lower band limit. Stop injections when the higher band limit is reached.

The first trials with top-up injection were performed in June 2001 and subsequent laundry shifts were done using it. For user operation it was decided to switch to the Frequent Injection mode in the middle of September 2001. The latter mode is the preferred on for our currently operating beamlines.

Both modes were operated with the injector system in single bunch operation, since the multi bunch mode of the gun did not allow to leave a clear gap in the storage ring beam pattern. The timing of the injection has no feedback on the actual filling pattern but is continuously stepped from bucket to bucket.

The first mode keeps the current constant to the level of one injection, between 0.1 and 0.5 mA usually, depending on the gun charge and the transfer efficiency of the injector. The latter mode allows for an arbitrary current band. Our current users prefer to have injections in intervals of about 2 to 4 minutes. These intervals can easily be adjusted using the second mode.

Figure 1 shows a typical top-up run for user operation. The beam current was held between 200 and 200.5 mA during that run. The startup of that run was delayed due to

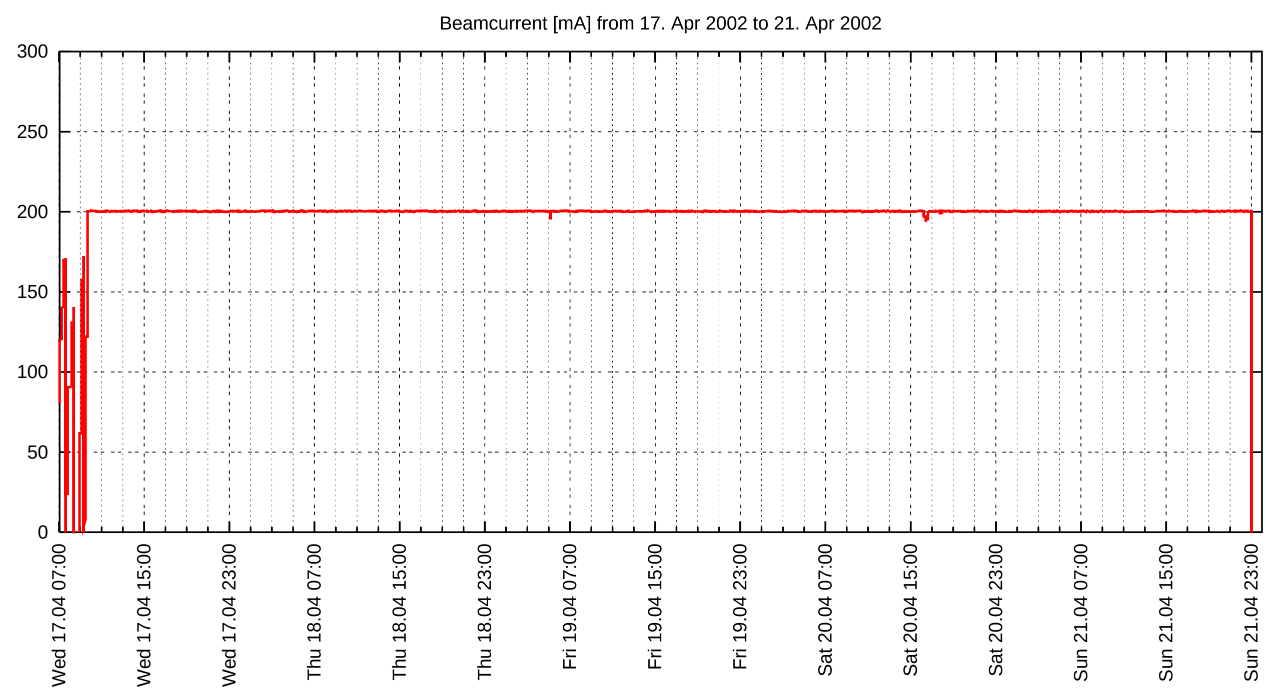


Figure 1: Beam current during a typical top-up run (week 16 of 2002).

RF problems. After the startup at 10 am on the first day, the current dropped two times a few milliampere below the design current during the next four days. In both cases a Linac modulator switched off due to arcs. The problem was solved during the next machine shift.

## 4 EXPERIENCES

### *4.1 Radiation Safety*

A very crucial point was to get the radiation safety allowance to inject with open beam shutters. It had to be proved just from the beginning, that the radiation level in the optical hutches stays below the required thresholds. Already the first measurements in June 2001 showed that the top-up operation mode does not increase at all the radiation level for an open insertion device and open beam shutter. At closed gap, the radiation level near the axis increased by a factor of two. This is still far below the required radiation limit for closed gap operation.

### *4.2 Machine Performance*

The injector system consisting of the $100 MeV$ Linac and the $2.4 GeV$ booster proved to work reliable. The combination of the low emittance beam coming from the booster, the well matched transfer line and the carefully adjusted kicker bump allow to almost reach 100% transfer efficiency from the booster to the storage ring.

Scraper measurements were done to determine the minimum gap possible without degradation of the injection efficiency. The results showed, that a minimum gap of $3.5 mm$ should be possible for future in-vacuum devices.

Figure 2 shows the residual injection kick by the injection bump. It vertical kick is in the order of $100 \mu m$ at the

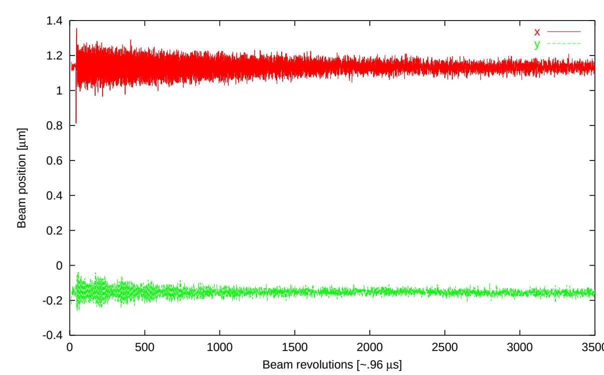


Figure 2: Measured orbit oscillations by the injection kick.

tune BPM with a beta function of approx. $13 m$ in both planes. This corresponds to approx. $30 \mu m$ vertical distortion at the position of the insertion devices. Many experiments are not sensible to the distortions, since the kick is damped out within nearly a millisecond. A gate signal can reject data samples measured during that millisecond if the distortion has influence on the experiment.

### *4.3 Reduction of Machine Drifts*

It turned out that drifts of the storage are strongly reduced in top-up operation. Figure 3 shows the horizontal

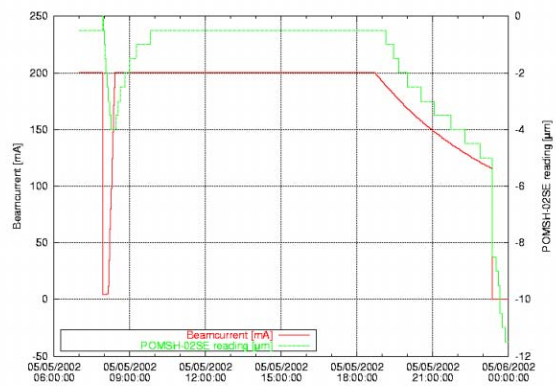


Figure 3: Movements of a BPM relative to its girder in decaying beam and top-up mode.

movement of one electron BPM relative to its girder using the POMS system[5].

The machine was operated in decaying beam mode for the last four hours of the run. During that time the BPM drifted nearly 5 $\mu m$, while there was no drift during top-up operation. The figure shows also the excellent reproducibility of the machine after a beam-loss, earlier during that run: within 0.5 $\mu m$ the BPM moved back to the same position.

The particle losses during injection are measured by loss monitors at the small gap in-vacuum undulator U24 [6]. Figure 4 shows the loss counter rates of the three counters. It shows that the integrated loss rate is only very little increased due to the injections. Large losses could not only disturb the data acquisition of the experiments, they would also endanger the insertion device, since the undulator could be partially demagnetized by the penetrating particles [7].

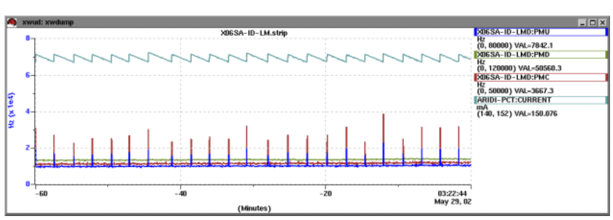


Figure 4: Particle losses during injection, measured by three loss monitors at the small gap in-vacuum undulator.

## 4.4 *Beamline Distortions*

The four currently operating beamlines see no significant distortion due to the injection. Figure 5 shows the spot stability measured for the protein crystallography beamline. The measured stability is not yet at the design values of the beamline, but within the current noise level of the measurement.

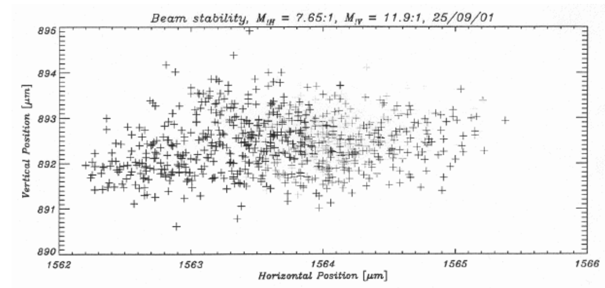


Figure 5: 1000 measurements of the spot center measured at a detector of the protein crystallography beamline.

All beamlines have gate signals available to disable data acquisition during injections, but no beamline is actually using this signal yet. This will probably change with a further increase in sensibility of the performed experiments.

## 5 CONCLUSION

The SLS operates in top-up mode for nearly one year now. We were able to generate very stable machine conditions in this operation mode. The constant thermal load on the beamline optics and the constant photon beam intensity allowed for a very good optimization of the beamlines.

The injector system proved to work highly reliable. Excellent injection efficiency is reached with the effect, that no significant distortions are measured at the experiments due to injections. Altogether this lead to highly satisfied users.

## 6 REFERENCES

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