

OPERATION OF THE SWISS LIGHT SOURCE: TOP-UP FOR HIGHEST PERFORMANCE

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Abstract

The Swiss Light Source (SLS) is now in its third year of user operation. Right from the beginning top-up has been the standard mode of operation. Operation at a fixed beam current makes many applications easier to implement and allows to push several systems to higher performance. It enabled us to reach an excellent orbit stability and reproducibility and it made our users insensitive to shortened beam lifetimes. We succeeded to satisfy the high demands on the availability of the injector system and our flexible timing system even allows for a parallel usage of the Linac for experiments during top-up operation. The impact of top-up operation on the overall performance of the SLS is document in this paper.

INTRODUCTION

In top-up operation the beam losses are compensated by frequent injections into the storage ring. The beam current is thereby kept constant to a few per mille (see Fig. 1.)

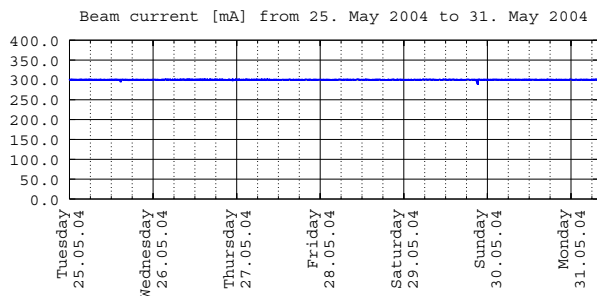


Figure 1: Beam current for one SLS user operation week.

Top-up was introduced at 3rd generation light sources to overcome beam lifetime limitations and to keep a constant photon flux for a thermal equilibrium at the beamlines.

The SLS was designed to be operated in top-up mode, e.g. by designing a low emittance, full energy injector with low power consumption [1] and stable semiconductor pulsers for the injection kickers [2].

SLS USER DEMANDS FOR TOP-UP

The SLS user demands are not specific to top-up: maximum availability and optimal stability of the beam are the primary requests.

In 2004 we reached so far an average availability of 97.9% and a mean time between two beam losses (MTBF) of about 53 hours (See fig. 2.) In 2002 we reached 94% availability and 30 hours MTBF, in 2003 at the same availability an MTBF of 45.9 hours. One single event, a vacuum

leak, caused about 50% of the downtime in 2003. Top-up is also the favored operation mode for most users because they regard a refilling as an user time interruption similar to a beam downtime. Therefore only top-up allows for real uninterrupted user operation.

With the successful commissioning of our fast orbit feedback in December 2003 we were able to stabilize the beam down to a sub-micron level [3]. A prerequisite for such a high stability is a thermal equilibrium of the storage ring. Otherwise the reference points themselves would move with the thermal expansion of the vacuum chamber. The steady state operation at the SLS is already achieved about one hour after reaching the top-up current. The relative movements of the vacuum chamber to the magnets at each BPM go down to a sub-micron level [4].

The lifetime independence by top-up helps to increase the availability. An example for the latter was an incident last fall: a vacuum leak in one sector was repaired in-situ and resulted in a reduced lifetime at restart (See fig. 3.)

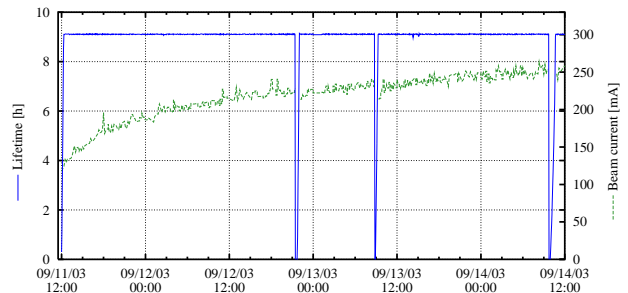


Figure 3: Recovery after a vacuum incident: the short lifetime of 4 hours was transparent to the users due to top-up.

Top-up helped two fold: first, the users could work with the promised beam current. The reduced lifetime was only recognized by them from a slightly increased background noise by higher particle losses. And second the desorption cleaning of the vacuum chamber did proceed faster, due to the higher average beam current from top-up.

SLS OPERATION DEMANDS FOR TOP-UP

Economical Operation and Safety

An efficient use of the resources is very important for the operation of the SLS. The machine is operated together with a proton cyclotron complex. This complex consists of three independently used proton accelerators. All accelerators are operated by the same team of two to three operators. The SLS should in the normal case run without any intervention of the operator. Therefore we put a lot of

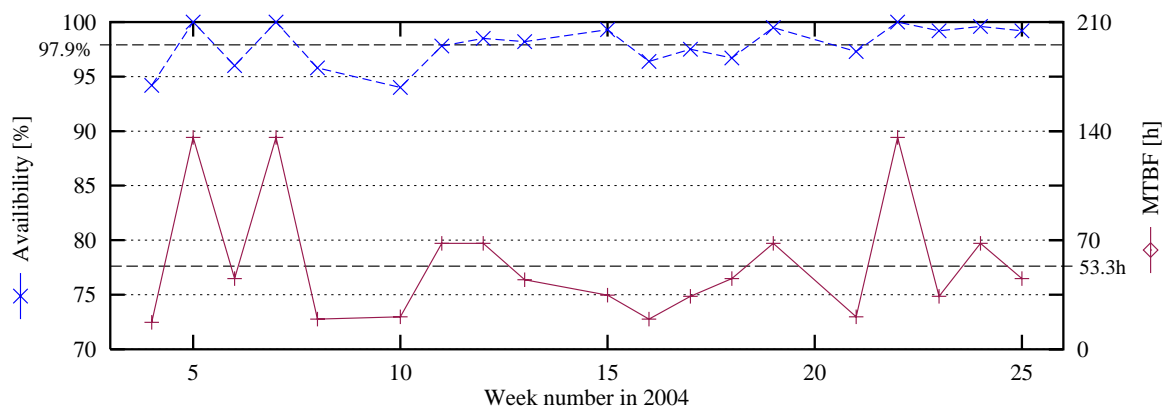


Figure 2: SLS operation statistics for the first half of 2004. The average availability in user operation was 97.9% and the mean time between two beam losses (MTBF) was about 53 hours.

effort to reach a high level of automation and a high level of operation security. The fully automated process for top-up needs to be fail-safe: the injection must stop at a beam loss and a failure of the top-up application or of the beam current measurement must not lead to an uncontrolled increase of the beam current.

Special attention was therefore given to a redundant measurement of the beam current. We chose the median current calculated from the intensity signals of the 74 electron beam position monitors (BPMs) as a robust backup measurement. This can be used as a fall-back for the beam current feedback of top-up and for a software interlock on the allowed maximum beam current.

We do not allow top-up down to zero beam current. In case of a beam loss the operator needs to open all gaps of the permanent magnet insertion devices by one button click to enable the injection into the storage ring. This interlock is necessary since no control of the orbit is possible without beam and a malfunction of the injection could therefore cause damage to the permanent magnets. When a minimum beam current of 50 mA is reached and the orbit feedback is started again, one button click closes all insertion devices to the previous gap positions.

Supporting Applications for Top-up

In top-up operation at the SLS a few injections occur about every three minutes. In case of problems with the injector system it was hence very difficult to optimize the transfer rate. To facilitate the maintenance of the Linac we introduced a special mode where the injection in the booster runs continuously and only the extraction trigger from the booster is gated by the top-up application [5]. In this mode the beam is accelerated to 2.4 GeV in the booster and then decelerated down to about 100 MeV again to be dumped at low energy. This allows for the optimization of the Linac, Linac to booster transfer and the injection into the booster.

An additional demand is the possibility for a parallel usage of the Linac for experiments like the electro-optical

sampling experiment [6]. We build a timing application that swaps the setup whenever a top-up refill is required and swaps back to the experimental setup a few seconds later when the refilling finished [5].

Fluctuation in the injection rate or differences in the lifetime of individual parts of the pattern can easily lead to a deviation from the desired filling pattern if top-up is running for several days without beam interruption. A feedback on the filling pattern was therefore implemented [7]. As a result of this feedback we were able to further suppress residual oscillations of the photon beam at the beamlines, caused by the charge distribution sensitivity of the BPMs [3].

The filling pattern feedback currently supports two filling modes: a bunch train of consecutive buckets and a hybrid mode, where a single bucket is filled in addition to the bunch train. The single bunch is placed in the middle of the gap and allows for time resolved measurements [5]. Figure 4 shows the charge distribution of a typical hybrid filling of the SLS. The charge of the single bucket is individual adjustable.

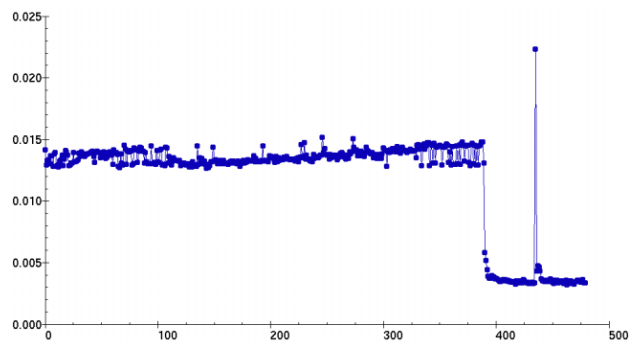


Figure 4: Charge per bucket number for the hybrid filling of the SLS: 380 consecutive buckets out of 480 filled and an additional bunch in the middle of the gap for time resolved measurements.

DIAGNOSTICS AND RF

A calibration with the beam current is very important for many systems that interact with the beam. Those calibrations can be driven to a much higher extend with the beam current being constant to a per mille level. Examples are the Beam Position Monitor System or the different RF systems. In case of the 3rd harmonic Cavity top-up will increase the lifetime of the system. Because between 300 and 400 mA it would be necessary to adjust the tuning of the cavity: a setting that would produce the required bunch lengthening at 300 mA would destabilize the beam at 400 mA. Since the tuning is done by elastic deformation each tuning brings mechanical stress to the cavities. With a refilling every 8 hours this tuning would be necessary six times a day. In top-up operation the tuning is done only at a beam loss, i.e. at the SLS two times every 50 hours.

The measurement of the beam lifetime is slightly more complicated in top-up. A beam lifetime of about 10 hours is very difficult to be measured precisely in the two to three minutes between two injections. An algorithm was therefore implemented that takes the lifetime in the previous periods without injection into account to calculate a more exact value for the lifetime [8]. A check is performed to quickly react on changes in the lifetime. During injections the same application calculate the injection rate by a fit on the beam current data.

THE SLS INJECTOR SYSTEM

For top-up the injector system has to run continuously. We run a 100 MeV Linac with a period of 320 ms, synchronous to the mains. The beam is then injected into a full energy booster that cycles with the same period. The booster has a FODO lattice with many small, low gap combined function magnets. This generates the small equilibrium emittance of 7 nmrad at 2.4 GeV [1].

Due to the frequent injections during top-up the time for scheduled maintenance of the injector is limited to the machine development shifts and shutdowns. An outage of the injector will directly be recognized by the users. But it will only cause a switch to decaying beam operation from the top beam current. An example of the minor impact on the users from rather severe Linac problems is shown in figure 5. The outage of Linac always occurs at the maximum current. In decaying beam operation it would most likely

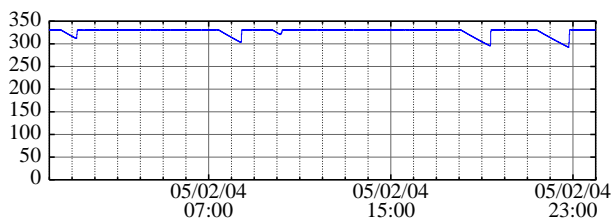


Figure 5: The beam current dropped due to several Linac outages for up to 11% below the top-up current.

occur when a refilling was scheduled, i.e. at an already low beam current. Therefore an injector outage has usually the lesser impact on the users in top-up.

Top-up operation is less sensitive to degradation of the injection rate, too. While a refilling would require more time in this case, top-up just require more injections. Since our users are not sensitive to injections we can tolerate a poor injection rate until the end of the user run.

OUTLOOK

The support applications for top-up at the SLS are still developing. The filling pattern application will be enhanced to allow the definition of arbitrary target filling patterns. This will require a modulation of the injected charge depending on the required charge for the chosen bucket to inject into.

SUMMARY

Top-up simplifies the operation of an accelerator: at a constant beam current the machine is in thermal equilibrium, all systems can be tuned to their optimum for the operating current and a drastically reduced dynamic range is acceptable for all measurements. Even the operation statistics benefit from top-up, starting with the fact that there are no periodic interruptions for refilling and profiting from the lesser impact of lifetime degradations and of temporary injector problems.

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