APPLICATIONS FOR TOP-UP OPERATION AT THE SWISS LIGHT SOURCE

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Abstract

The Swiss Light Source (SLS) is a medium energy 3rd generation light source, optimized for minigap undulators. A Touschek-dominated beam lifetime of 3.5 h is expected for the design current of 400 mA in the presence of undulators with 4 mm minimum 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. We will describe the applications, which we use for this specific mode of operation.

1 INTRODUCTION

Optimal operation of a synchrotron light source has some conflicting constraints. To achieve a high brightness, low beam emittance and high currents are required. However, these lead to the shortening of beam lifetime, which in turn reduces the useful beam time for the experimenters. One way to circumvent these restrictions is to use top-up injection, where a small charge is injected every now and then to maintain a constant current level in the storage ring. For SLS, top-up operation was planned from the beginning, and thus the first top-up operation was started very soon after initial commissioning.

The injector as well as the beamlines had to be prepared to handle this mode. The injector chain has to be operated constantly so it has to be reliable and stable. The SLS booster synchrotron [2] has a relatively low power consumption (200 kW at 3 Hz operation) that allows for a continuous top up. It also has a low emittance that allows efficient injection. The beamlines require a possibility to be notified when a top-up injection is about to happen, and have to be able to gate their detectors during the injections. The timing system has to be able to accurately target the injections so that the desired filling pattern can be maintained and to syncronise the operation of several elements. The injection kickers have to be carefully optimised for a minimum residual kick, so that the orbit disturbance during injection is minimized.

During top-up operation injections happen with the insertion device (ID) gaps closed. Precise setting and stability of the beam orbit is required to avoid damage to the permanent magnets in these devices.

In addition, many software applications are needed for the smooth and reliable operation of this mode.

2 TOP-UP INJECTION CONTROL

The top-up algorithm is in principle very simple. For operation, a lower threshold current and a deadband are defined. Whenever the beam current drops below the lower threshold, the injector is enabled for as many injection cycles as necessary to fill up the ring to the defined current (lower limit plus deadband.). The sequence of these actions is controlled and synchronised via the timing system. The relevant delays have to be set and the triggering of the relevant components (electron gun, injection and extraction kickers and septa, etc.) has to be enabled and disabled at correct times. The actions have to executed synchronously at multiple sub-controllers (EPICS-based IOCs) which otherwise are connected only through the computer network. The relevant IOCs have an event receiver card to receive the synchronization events and to trigger the appropriate actions at that IOC. The actions are synchronized to the 3 Hz operating cycle of the injector. In addition, before the injection starts the timing system sends out an event indicating that a top-up cycle is about to take place. When the injection is over, another event that indicates the end of cycle is sent.

The algorithm keeps the beam current constant within the defined deadband. The deadband can be adjusted to provide an interval between injections that is most suitable for the beamline experiments. Typically it is set so that injections occur every four to five minutes.

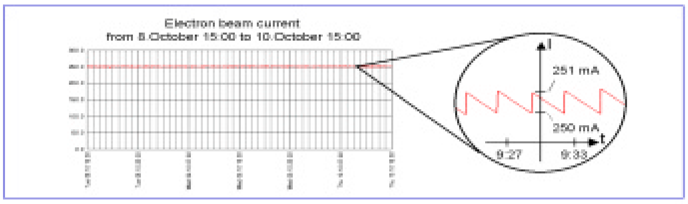

Figure 1: Two days of top-up operation at SLS.

3 FILLING PATTERN FEEDBACK

During long top-up runs, the filling pattern of the ring deteriorates if the injections are done without any feedback of the filling pattern. Beam instabilities may kick some buckets totally away, poorly optimized injector can leave some buckets with less current and so on. Re-optimizing the injector during operation is not always possible and in any case not easy, as the top-up cycles occur every few minutes.

For this reason we have implemented a method to feed back the filling pattern to the top-up application, so that the injections are done to RF buckets with lower charge. The charge in each bucket is read, the values sorted according to the bucket charge and the bucket numbers with the lowest charge are sent to the application that controls injection. At each top-up cycle the buckets with lowest charge are filled, and when the current limit is reached, the bucket charges are read again.

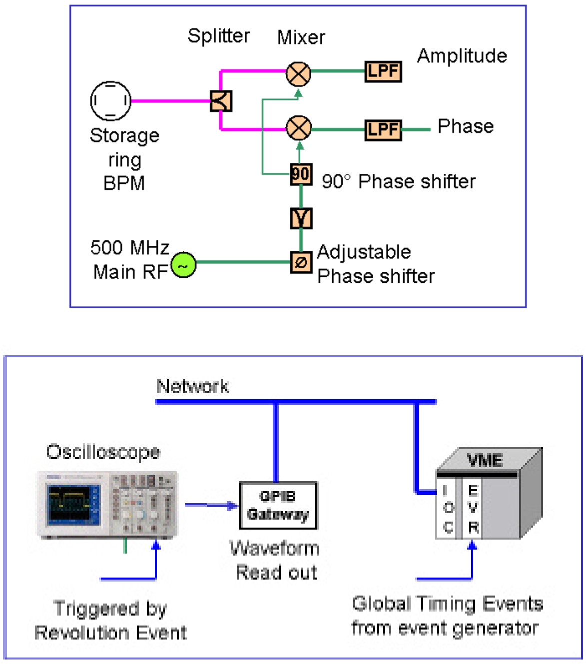

Figure 2. The filling pattern readout system.

The charges in the RF buckets are read with a system as shown in figure 3. The signal from a beam position monitor pickup is mixed with the accelerator RF signal and low-pass filtered to give the beam amplitude and phase. These signals are then fed into an oscilloscope. The amplitude signal trace is read out from the oscilloscope through a GPIB bridge to the control system. The raw amplitude data is first put into an EPICS waveform record. The data from this record is compressed to an array with number of points corresponding to the number of RF buckets in the storage ring. The compressed data that gives the charge in each bucket, associated with the corresponding bucket indices, is sorted to an ascending order,. After sorting the bucket indices are available in an array with the index of the bucket with the lowest charge first (however so that only the buckets that are supposed to be injected to are considered.)

When the beam current falls below the lower threshold, the bucket numbers from the array are fed into the appropriate timing system channels to set the delays in order to inject into the desired buckets. The values from the array are taken one at a time for each injection cycle until the charge limit has been reached. At the end of the cycle, the timing system sends out an event that signals that the injection is done. This event is used to trigger the pattern readout process to recalculate the charges in each bucket for the next top-up cycle.

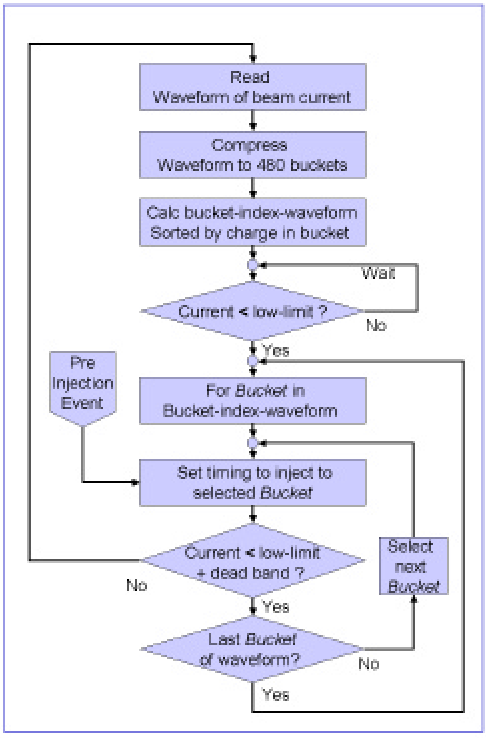

Figure 3. Flow diagram of the filling pattern feedback.

4 OPERATION REQUIREMENTS

During the top-up runs, the accelerator runs in an automatized mode. If nothing goes wrong, the operation can go on for several days without any intervention. However, it is very important that any possible failures are clearly indicated to the operators, as if something does go wrong, it could have severe consequences. And in any case the operator has to find out any possible problems and correct them as soon as possible.

3.1 Alarms

The operators need to be alerted as soon as an anomaly in the injector system has been recognized. When something is wrong in the injector chain, the top-up does not reach the set threshold. This can be notifield by a beamdrop alarm that triggers an acoustic alarm if the beam current drops for more than 0.1 mA below the top-up lower threshold current. All the beamdrops are logged and documented to give feedback concerning reliability of the injector components.

Maintaining a good beam orbit is of primary importance for the reliable operation. A bad orbit influences the experiments and can in the worst case lead to severe problems if the beam starts to locally heat the vacuum chamber. During top-up operation, the orbit feedback must be switched on. An orbit RMS deviation of more than 20 ?m raises acoustic alarm.

3.2 Insertion Device Protection

The top-up injection occurs with ID gaps closed. As the SLS IDs are operated with very small gaps and some are even in-vacuum devices, a bad injection could lead to damage to the permanent magnet material of the devices. To prevent this kind of damage, there are certain restrictions in operation. First, the top-up injection should only take place when the beam orbit is stable and can be corrected. That implies that during an initial fill the gaps have to be opened for injection. Above a certain current limit, the orbit can be reliably corrected and is from then on very stable. At this point the gaps can be closed. An application to force opening of the gaps for re-injection from the control room has been developed. This has to happen even when an automatised energy scan at the beamline was in progress. The scan is interrupted and nominally it could continue after the forced opening, but it is then up to the user to decide whether the scan should be repeated from the beginning.

3.3 Diagnostics

During top-up operation, the normal measurement and calculation of beam parameters is disturbed by the injections. For instance, a beam lifetime measurement based on beam charge decay clearly makes little sense when if the charge is measured over an injection. The Lifetime measurement has to be done between injections. Another parameter that needs to be constantly and automatically monitored are the betatron tunes. For normal operation we have been using the injection kick for tune measurement. However, when there are no injections, the kicker magnets are not pulsed and thus the tune cannot be reliably measured. For this purpose, the top-up application triggers a timing event to be sent before and after the top-up cycle. The relevant components like the tune pickup BPM listen to these events and operate accordingly. For example, the tune is only measured when the top-up is on and the injection kickers are activated.

To recognize anomalies in injection (bad orbit, etc.) particle loss monitors have been installed close to the insertion devices. Basically the loss monitors are either photomultipliers or photodiodes that produce pulses and the pulse rates are proportional to the beam loss at these points. Especially the photomultipliers have proved to be very sensitive and accurate measurement of the beam losses and are constantly monitored to record the beam loss levels.

As a measure of the injector efficiency, the average injection rate per top-up cycle is measured. This gives us feedback concerning the stability of the injector and an indication when tuning would be necessary.

The residual injection kick is minimized with the help of the digital beam position monitors. The BPM system can provide turn-by turn position data so that the orbit disturbance during injection can be measured and displayed.

5 CONCLUSIONS AND FUTURE WORK

The top-up injection was adopted very early as the default mode for the SLS operation. This has brought s a number of advantages, like improved availability of the beam for users because less fills (when no experiments can take place) are required, the current and thus the photon flux remains constant, and, although not expected, the extreme stability of the beam after some time of constant current operation when all components have reached a thermal equilibrium.

The flexibility of the filling pattern definition has to be improved, to be able to easily define modes like a “camshaft” mode, where there is a range of buckets with constant charge, plus a single bucket with empty buckets before and after.

The filling pattern reading and feedback needs further development before it can be used as a default operating mode for user runs. At the moment it needs careful tuning of the application at startup, especially to check that the waveform read from the oscilloscope corresponds to what is really injected into the storage ring.

The signals to indicate that an injection is about to occur and to gate the measurements at the beamlines are in place but not yet in use by any of the experiments. They should be taken into use and based on the user experience some further development of the top-up applications is probably required.

6 ACKNOWLEDGEMENTS

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7 REFERENCES

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