PLAN TO UPGRADE THE ADVANCED LIGHT SOURCE TO TOP-OFF INJECTION OPERATION*

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Abstract

The brightness and thermal stability of the Advanced Light Source (ALS) is lifetime limited. Brightness improvements such as narrower gap insertion devices, smaller emittance coupling, and higher currents all result in reduced lifetimes. In addition electron beam current changes over a fill impact the thermal stability of both the storage ring and beamlines. In order to mitigate these limitations there is a plan to upgrade the injector of the ALS to full energy injection and to operate in a quasi-continuous (Top-Off) injection operation. With Top-Off, the ALS will increase its time-averaged current by two, reduce the vertical emittance, and operate with smaller gap insertion devices. In this paper we describe our upgrade plan.

INTRODUCTION

The Advanced Light Source (ALS) is a 3rd generation synchrotron light source optimized for the generation of VUV and Soft X-ray radiation. In the VUV and Soft X-ray spectral regions the ALS is one of the world's brightest sources of radiation. Exploitation of the high ALS brightness translates into three areas: (1) high resolving power for spectroscopy; (2) high spatial resolution for microscopy and (3) high coherence for experiments such as speckle. In many of these areas there is a desire for even further increases in the ALS brightness for many "photon starved" experiments.

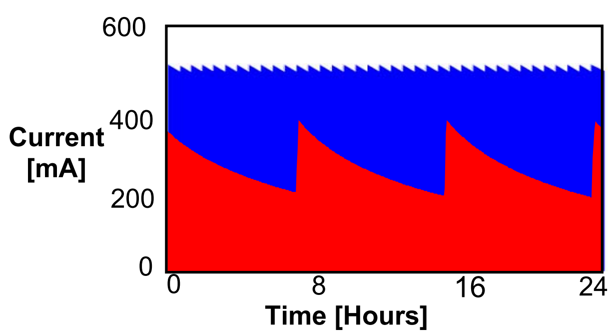

Figure 1. Beam current in the ALS over one day before Top-Off (red) and after Top-Off (blue).

Currently the practical achievable brightness of the ALS is beam lifetime limited. In principle it is possible to significantly increase the beam brightness by operating with higher currents, smaller beam sizes, and smaller insertion device gaps. However these operating conditions come with a penalty – a smaller beam lifetime. The primary limitation of the beam lifetime is intrabeam (Touschek) scattering. Fig. [1] shows a typical beam current history for one day. The storage ring current is refilled every 8 hours. Between fills the beam current decays from 400 to 200 mA with an average beam current of 250 mA. Reducing the lifetime further is unacceptable to many of ALS users.

In order to alleviate the impact of small beam lifetimes, the ALS is planning to upgrade the facility in order to operate in a quasi-continuous injection mode (Top-Off). In this mode beam is injected into the ring approximately every half minute to replenish the lost electrons, keeping the beam current roughly constant. Operating the ring with constant beam current has an additional advantage. Top-Off operation would improve the thermal stability of many of the storage ring and beamline components. Already quasi-continuous injection is the standard operating mode of several light sources – APS[1], SLS[2], Spring-8[3]. The short term plan is to operate the ALS with Top-Off injection at 500 mA (see Fig. 1). This would double the integrated beam current and allow other improvements in beam brightness.

GENERAL PLAN

Several upgrades to the facility are necessary to enable Top-Off operation. Currently the ALS injection system consists of a 50 MeV linac and a 1.5 GeV booster. The beam is injected into the storage ring at 1.5 GeV and then the beam energy is ramped in the storage ring to 1.9 GeV – the nominal user energy. Top-Off operation requires a full energy injector. Therefore the maximum injection energy will need to be increased from 1.5 GeV to 1.9 GeV.

Second, Top-Off requires an upgrade of the radiation monitoring and interlock safety systems. This is to ensure safe operation while injecting with the beamline shutters open. In our present operational mode the beamline safety shutters remain closed during injection

Third, Top-Off requires improvements to be made to the fast pulsing magnets to minimize the distortion of the stored beam during the injection process. The goal is to make the injection process as transparent to users as possible. In addition a gating signal will be distributed that can be used for those users who are affected by the injection process.

This year the full scope of the upgrade is being evaluated. The plan is that the upgrade will be completed by mid 2007. The transition to Top-Off will be transparent and take place in typical (1.5 month) yearly shutdowns

USER REQUIREMENTS AND PARAMETERS

The exact scope of the Top-Off upgrade depends upon ALS user requirements. The ALS has a large and diverse user community using a variety of experimental techniques. One of the main activities in 2004 was to work with the user community to evaluate the impact of Top-Off on the various types of experiments. There were several issues that needed to be evaluated early in the upgrade process to define the scope of the project.

- What is the allowable orbit disturbance during injection?
- Can a gating signal be used?
- Should injection be equally spaced in time or equally spaced in current drop?
- Should injection be made in one pulse or several pulses (burst mode)?
- What is the allowable incremental change in current when topping up?
- Should we use Top-Off during 2-bunch operational mode?

To answer these questions, users representing the various different experimental techniques were consulted. In addition accelerator physics shift time was devoted to studying the impact of the Top-Off on the users.

Effect of Injection Transients

The accelerator physics shifts addressed one of the main concerns for users – the perturbation of the pulsed storage ring injection magnets on the stored beam. There are 6 pulsed magnets in one straight section – a thin and a thick septum magnet surrounded by four bump magnets (two on each side). These magnets can create two types of perturbations. The first is due to the four bump magnets not producing a perfectly closed orbit bump. This causes a fast beam oscillation in the horizontal and vertical plane. The effect can be seen in Fig. 2. The beam oscillation translates into an increase in the beam size. For reference the beam size is 300 µm horizontally and 20 µm vertically in the insertion device straights. The duration is short (~100 µs). The reason that the effect is so short is that the oscillation is quickly damped by the coupled bunch transverse feedback systems. The second beam perturbation is an orbit drift due to the decay of eddy current fields created when the thick Septum is pulsed. This duration is long (~ 20 ms) and can be seen in Fig. 3.

In order to determine the impact of the injection transients, user data was taken while turning on and off the Septum and Bump magnets. The result of these studies showed that most of the experiments were not sensitive to the injection transients. The only types of experiments that were sensitive were microscopes with short integration times. By far the most sensitive experiments were the scanning transmission x-ray microscopes (STXM). During a STXM experiment the microscope is scanning over a sample counting photons for as little as 100 µs to measure each point. The STXM users could see effects of both the Bumps and the Septum. A result of a STXM experiment can be seen in Fig. 4. The dip is due to the effect of the Septum. The STXM experiments are so sensitive that it probably will not be easy to make the injection process transparent. However the STXM users felt that they could easily adapt to a gating signal as long as the injection pulses were not spaced too close together.

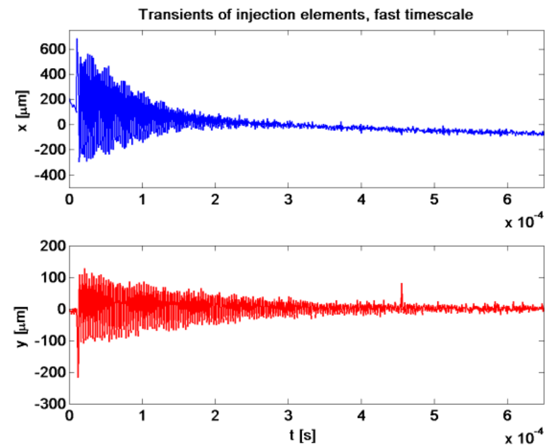

Figure 2. Horizontal (top) and vertical (bottom) orbit oscillations excited by the injection bumps in the insertion device straights.

Besides STXM there were a few other types of experiments that were sensitive to injection transients coming from the Septum magnet. As a result a study is in progress to improve the effect of the Septum magnet.

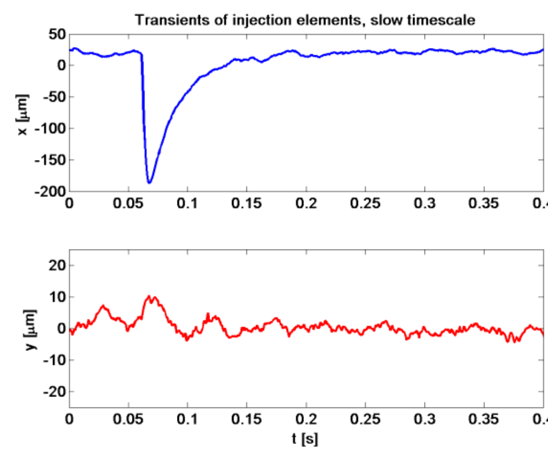

Figure 3. Horizontal (top) and vertical (bottom) orbit shifts created by eddy currents in the injection Septum in the insertion device straights.

The conclusion of the studies and subsequent discussions with users was that all those who were affected by the injection transients could use a gating signal. Also the users strongly preferred that the injection process be made in a single shot equally spaced in time (i.e. no burst mode). This all leads to single multi-bunch injection.

Top-Off parameters

The actual time between fills is a function of the electron beam parameters and depends upon such things as the acceptable change in current with refilling and the beam lifetime. The beam lifetime in turn depends upon the vertical emittance. Currently the vertical emittance of the storage ring is adjusted to about 150 pm rad. In accelerator physics shifts the vertical emittance has been reduced to 5 pm rad [5]. The benefits of the very small vertical emittances can not be realized due to beamline mirror imperfections. In Table 1 the present ALS parameters are compared with a possible set of parameters after Top-Off. The after Top-Off parameters show a reasonable balance between emittance, filling time, and percent current change during a fill. Of course the actual values may be somewhat different and can be easily adjusted to optimize the situation for users.

Parameter	Before Top-Off	After Top-Off
Vertical emittance [pm-rad]	150	30
Vertical beam size in straights [µm]	23	10
Vertical divergence in straights [µrad]	6	3
Time between fills	8 hours	30 s
Percent current change during fill	100 %	0.3%

Table 1. Comparison of present ALS parameters and possible parameters after Top-Off.

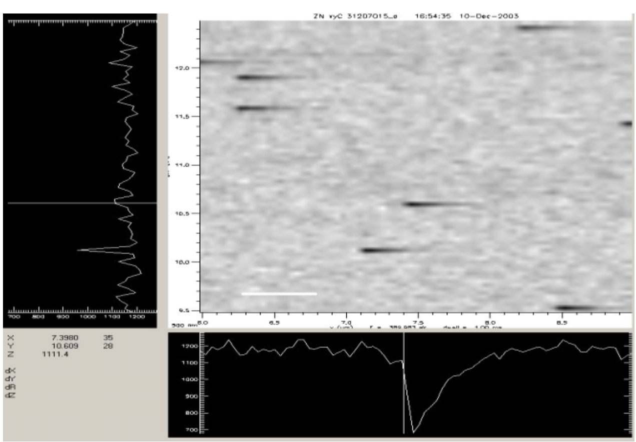

Figure 4. A STXM scan performed while the Septum was being pulsed. The effect was nearly a 50% change in the signal level. The dark streaks on the upper right plot occur during injection. The bottom intensity plot has a full time of 75 ms. Courtesy of Tolek Tyliszczak**.**

Another feature that will be added to the Top-Off upgrade is the ability to get rid of parasitic bunches in the injection system so that only the targeted bunches are filled. This is important in few-bunch operation where users demand parasitic contamination from untargeted bunches be less 0.01% of the main bunches. Currently the cleaning is done in the main ring prior to giving the beam back to users but this is impractical in Top-Off. Cleaning in the booster has already been demonstrated at Spring-8 [5] and ESRF [6].

RADIATION SAFETY

Effort is underway this year to evaluate the changes that are necessary to the safety systems to allow injection with the beamline shutters open. There are two issues being studied – need to ensure that injected electrons can not travel down a user beam line and that injected electrons do not significantly increase the amount of bremstrahlung radiation. Most likely this will result in two additions to the radiation safety systems. The first is to prevent injection with the shutters open unless there is stored beam. The second is that radiation monitors located near the first optic on the beamlines will be included in the interlock. The exact details of the system will be determined this year.

CONCLUSION

The Top-Off upgrade of the ALS is rapidly developing. Once implemented there will be immediate benefits in both brightness and stability for the users. It will also allow for smaller gap devices and more flexible modes of operation.

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