STATUS OF THE TOP-OFF UPGRADE OF THE ALS*

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Abstract

In order to provide higher brightness and better stability, the ALS is being upgraded to top-off injection. One main part of the top-off modifications is an upgrade of the booster as well as extraction and injection elements and the transfer line for full energy. Further upgrades include new diagnostics, improved controls and timing system, and new radiation safety systems (monitors and interlocks).

INTRODUCTION

The Advanced Light Source (ALS) is a third-generation source located at Lawrence Berkeley National Laboratory that has been operating for over a decade and is generating forefront science in many areas. However, the ALS was one of the first third-generation machines to be built, and storage rings currently being commissioned will provide higher brightness than achievable at the ALS so far.

The main possibilities to increase the brightness of the ALS are increasing the time-averaged current, reducing the beam size, and reducing the insertion device gaps. Currently those changes would result in (unacceptably) short lifetime. With continuous injection (top-off [1]), the importance of this lifetime impediment can be reduced significantly. Fig. 1 shows a comparison of the brightness of planned, new ALS insertion devices with the upgraded beam parameters to the typical brightness of a current ALS undulator. It also shows the brightness expected with proposed insertion devices at newer intermediate energy light sources. One can see that the upgraded ALS will remain competitive, with the main improvements coming from the smaller vertical emittance and the smaller physical gaps of the undulators.

PROJECT STATUS

The planning for the top-off upgrade started in 2004 with a conceptual design phase [2]. The conceptual design report [3] was finished by the end of 2004. During the conceptual design phase, all items that presented a significant technical risk have been studied in detail and no showstoppers were found. One particular area of risk consisted of the pulsed extraction magnets [4, 5] in the booster synchrotron and the pulsed injection magnets in the storage ring. However, after extensive simulations and measurements using newly built pulsers as well as newly assembled spare magnets, and some modifications of the injection geometry, it was determined that all existing pulsed magnets could be upgraded relatively easily for full energy injection.

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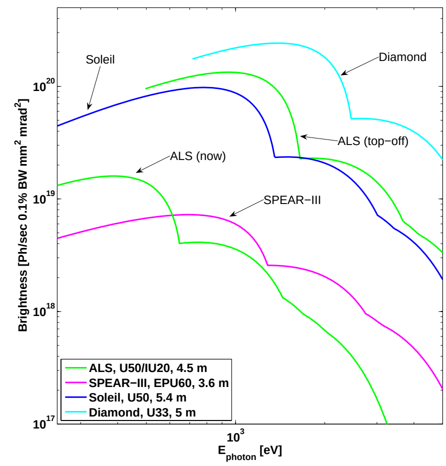

Figure 1: Comparison of the brightness around 1 keV of a 4.5 m long U50 with the current ALS parameters and an in-vacuum IU20 with top-off beam parameters to the brightness of proposed undulator sources at newer interemdiate energy light sources.

The project started in earnest in early 2005, when the funding for the main part of the upgrade was received. Detailed design of all long lead items followed. The main areas of work are:

- New power supplies and a new RF transmitter [6] to make the booster capable of full energy injection (upgrade from 1.5 to 1.95 GeV booster energy).
- New pulsers and modifications to all pulsed extraction and injection magnets in booster and storage ring.
- New power supplies to upgrade the transfer line energy.
- Radiation safety systems (including monitors, collimators, interlocks, shielding).
- Upgrades to timing systems, controls, diagnostics [7].
- Improved bunch cleaning techniques compatible with top-off.

At the moment, most components are being either manufactured or are already being tested. The plan is to complete the injector upgrade for full energy injection during a shutdown from October to December of 2006 and migrate to top-off injection during the following six months. Regulatory approval of injection with safety shutters open is expected for early 2007.

INJECTION TRANSIENTS

The injection processes create transient orbit distortions on the stored beam. Dedicated test shifts showed that only a small subset of users was adversely affected by those injection transients. To reduce the number of users that can see any adverse effect of the injection transient further, the stray field of the septum magnets was studied in detail. Simulations showed that using a simple modification of the thick septum magnet pulser, it is possible to reduce the delayed stray field by about one order of magnitude. Measurements both on a magnetic measurement bench and using the beam in the storage ring verified this improvement (see Fig. 2).

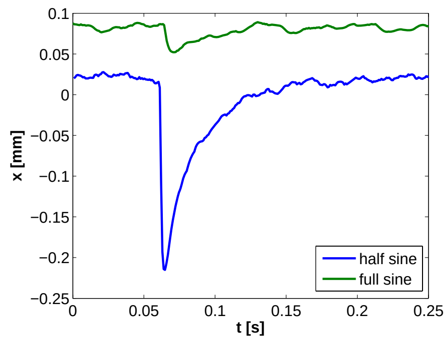

Figure 2: Transient horizontal orbit distortion induced by delayed eddy currents in the thick septum magnets. Using a full sine current waveform instead of a half sine reduces the magnitude by a factor of 10.

Faster beam position transients caused by the nonclosure of the fast injection bump are minimized effectively using the powerful multibunch feedback systems of the ALS. With optimized settings of the feedbacks, the transients last for less than 200 μs, much shorter than the radiation damping time of more than 5 ms.

RADIATION SAFETY

One very important aspect of the top-off upgrade is radiation safety. Since injection will occur with safety shutters to all beamlines open, new challenges arise. In addition, the higher beam current and smaller emittances producing higher brightness after the upgrade will also increase the electron loss rate from the storage ring, potentially increasing overall radiation levels. As part of the migration to top-off injection, regulatory approval has to be obtained to change the ALS Final Safety Analysis Document (FSAD) addressing all of those issues.

The approach to address these challenges, which has been chosen at the ALS, follows closely what has been done at other places, which already use top-off injection, namely APS, ESRF, SLS, and Spring-8. It consists out of the installation of additional interlock systems, interlocked radiation monitors and locally shielded beam defining apertures, as well as extensive simulation studies and measurements using the storage ring.

Because the ALS is the lowest beam energy storage ring of those, there are some additional challenges. The Touschek lifetimes at the ALS are shorter than at all of the other places and because of the low beam energy, the first beamline optics at the ALS are in general openly accessible with minimal shielding, whereas at the other places they are surrounded by large hutches/exclusion zones.

Experimental Studies of Radiation Levels

In order to evaluate background radiation levels during injection, studies with the safety shutter on one beamline open have been conducted. To make these studies possible, significant upgrades were made to the shielding on one beamline (see Fig. 3). Approval for a change to the ALS FSAD allowing the injection studies was received in 2005. Radiation levels found with large missteering of the injected beam were acceptable. Newly installed aperture defining collimators (see Fig. 4) in locations away from beamline source points minimized the radiation levels further.

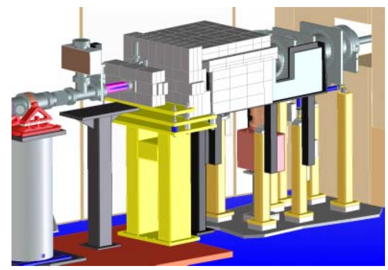

Figure 3: Additional lead shielding installed on ALS beamline 4 to enable top-off injection tests to study radiation levels with the safety shutter open.

A second potential issue are the routine particle losses due to the Touschek lifetime, as well as beam dumps due machine failures. Because the average beam currents in top-off will be higher by a factor of two and the lifetime shorter by a factor of about four because of the smaller emittance, the dose rates associated with those losses will increase substantially. The aperture defining collimators mentioned above allow to avoid expensive upgrades to the storage ring shielding and to protect the permanent magnet undulators from radiation damage by localizing beam losses away from undulators and beamline source points. It is also planned to add local lead shielding around those collimators.

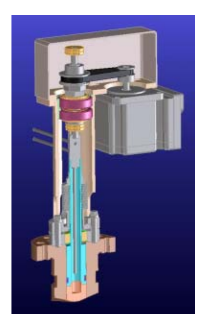

Figure 4: Beam aperture defining collimator used to locate beam losses away from the in-vacuum undulator and beamline sourcepoints.

All beam studies conducted so far show that the aperture defining collimators are very effective in localizing beam losses with a small penalty in overall lifetime.

Tracking Studies

Because the radiation dose rate of even one injected bunch of electrons propagating down a synchrotron light beamline could be dangerously high, this case has to be excluded with absolute certainty. This is even more true at the ALS compared to other rings operating in top-off, because the ALS is a soft x-ray source and many first optics at the ALS are not enclosed in hutches.

The approach we plan to use is similar to other facilities. It consists of an interlock system, that only allows injection with beamline shutters open, if there is stored beam in the storage ring, combined with tracking studies that show that no injected beam can get into a light beamline if there is stored beam.

For the tracking studies, a new tracking routine was implemented, since no codes were available that included all necessary effects [8]. Because of the very wide antechamber at the ALS, it is necessary to include the full, correct transverse field profile for all magnets. Originally, studies were conducted using backward tracking for beamline 2.1 (first dipole of arc 2), the ALS beamline closest to the injection point. It was found that no particles launched in the phase space of the beamline would make it back to the injection point for very wide ranges of beam energies and settings of all magnets in between. This showed that all .1 beamlines are safe in top-off. The condition is similar for all .0 beamlines (i.e. all undulator beamlines).

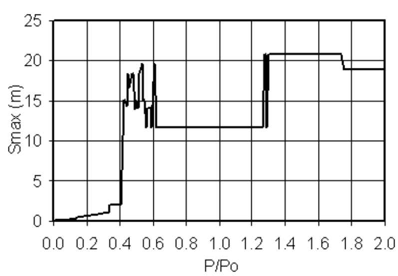

Figure 5: Maximum distance of particles launched backwards at beamline 2.1, the beamline closest to the injection point in the ALS. The injection point is at about 25 m distance from the beamline.

However, later studies showed that the situation particularly for the .3 beamlines emanating at 7.4^o of the 10^o center bend magnets of the ALS triple bend achromat is not as clear. Because these source points are close to the end of the bending magnets and because of the very wide ALS antechamber, work is still going on to demonstrate that these beamlines are safe. As a fallback solution in case the problem cannot be resolved, it is planned to install permanent magnets on the frontends clearing out any possible electrons in this subset of beamlines.

BUNCH CLEANING

Two-bunch operation is a very important operation mode of the ALS offered for about 4 weeks every year for time resolved studies. In order to provide a sufficiently clean fill pattern with parasitic bunch contamination in the 10^{-5} range, parasitic bunches have to be actively cleaned. The method employed at the ALS so far makes use of the tune shift with current and is incompatible with top-off operation. Therefore a new technique, first developed at SPring-8, for purifying the bunch fill pattern has been explored [9].

The technique is based upon mixing two signals. The first signal is generated from an existing sinusoidal signal generator. The second signal is generated by a fast 500 MHz multipurpose board that was developed by the ALS Electrical Engineering Instrumentation Group. The multipurpose board has a very large bandwidth, with no timing drift, is very reliable, and easy to program. The multipurpose board generates a signal that goes through zero at the time the bunches that the users want to save go past a kicker. The system has already been tested in two-bunch user operation and performed extremely well. All measurements so far indicate that it will be compatible with top-off operation.

CONCLUSIONS

The top-off upgrade of the ALS is well under way. It will allow significant improvements in brightness and stability and will keep the ALS competitive with the newest storage ring based light sources. All long term items necessary for the full energy upgrade of the injection system are under construction and several are already in the testing phase. The main installation shutdown will be starting in October 2006 and full energy injection should be achieved before the end of the year. Full top-off operation is expected in 2007. There has been significant progress in resolving the complex radiation safety issues associated with the upgrade. Localizing beam losses at aperture defining collimators works well, minimizing radiation dose rates elsewhere. There has also been significant progress in simulations of whether injected electrons could propagate down light beamlines, however those studies are not concluded, yet and fallback solutions are being studied for one subset of beamlines.

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