

STATUS OF THE TOP-OFF UPGRADE OF THE ALS*

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Abstract

The Advanced Light Source is currently being upgraded for top-off operation. This major facility upgrade will provide an improvement in brightness from soft x-ray undulators of about one order of magnitude and keep the ALS competitive with the newest intermediate energy light sources. Major components of the upgrade include making the booster synchrotron capable of full energy operation, radiation safety studies, improvements to interlocks and collimation systems, diagnostics upgrades as well as emittance improvements in the main storage ring. Most hardware necessary as part of the upgrade has been installed and commissioned. The radiation safety studies are making good progress and have passed a first outside peer review successfully.

INTRODUCTION

The Advanced Light Source (ALS) at Lawrence Berkeley National Laboratory has been operating for over a decade and is generating forefront science in many areas with more than 2200 users every year. However, the ALS was one of the earliest third-generation machines to be built, and storage rings recently 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. To be able to tolerate the shorter beam lifetimes that result from those changes the use of continuous injection (top-off [1]) is one essential component. Fig. 1 shows a comparison of the brightness of planned, new ALS insertion devices with the upgraded top-off beam parameters to the brightness of a current ALS undulator. It also shows the brightness expected at newer intermediate energy light sources which were commissioned recently. One can see that the upgraded ALS will remain competitive.

PROJECT STATUS

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. The project started in earnest in early 2005, when the funding for the main part of the up-

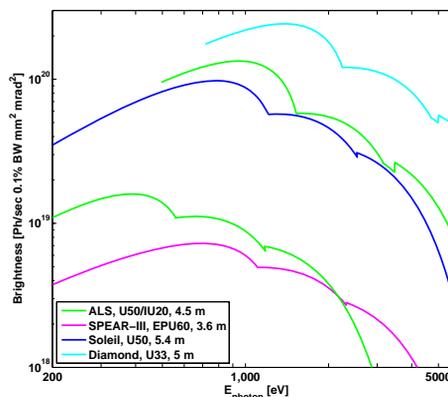


Figure 1: Comparison of the brightness around 1 keV of a 4.5 m long U50 with the current ALS parameters and an in-vacuum IU20 with top-off beam parameters to the brightness of proposed undulator sources at newer intermediate energy light sources.

grade was received. Detailed design of all long lead items followed. The main areas of work were:

- New power supplies and a new RF transmitter 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.
- Improved bunch cleaning techniques compatible with top-off.
- Radiation Safety studies to demonstrate that top-off operation of the ALS is safe.

Most hardware components were installed in late 2006 and successfully commissioned. However, problems with one of the new hardware components has prevented to migrate to full energy injection so far. In parallel radiation safety studies were conducted. They included experimental studies at the accelerator as well as very extensive tracking studies culminating in an outside review, which was completed successfully in April 2007. Regulatory approval of injection with safety shutters open is expected for fall 2007.

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Installation and Commissioning

During the last year, the major installation shutdown to upgrade the complete injector system for full energy injection was completed. The fall/winter 2006 installation shutdown was the longest shutdown for the ALS since it began operations in 1993. The focus of the shutdown was to complete the installations necessary for the upgrade to top off injection. The commissioning period afterwards did progress slowly due to major problems with the largest of the new power supplies for the booster synchrotron. The process of fully troubleshooting it is still ongoing and for the time being it is used in a partial configuration that does not yet allow full energy injection but in which it has worked very reliably. We expect the problem to be fully resolved within the next couple of months. Fig. 2 shows some examples of new hardware installed.



Figure 2: Example of newly installed hardware: New RF transmitter (IOT based); new controllers for small rsamped power supplies and rf amplitude (FPGA based).

With the completion of the 2006 shutdown and commissioning period the major hardware work for the top-off upgrade is complete. Further hardware work is relatively limited and consists of some additional radiation safety interlock systems and the gating signal distribution chassis which can be installed outside of major shutdowns. The main activity that needs to be completed before starting operation in top-off mode are very extensive radiation safety studies.

RADIATION SAFETY

Radiation safety is probably the most important and most challenging area of the top-off upgrade [4]. Since injection will occur with safety shutters to all beamlines open, additional radiation safety challenges arise compared to a decaying beam operation. As part of the migration to top-off injection, regulatory approval has to be obtained to change the ALS safety envelope addressing all of those issues.

We closely considered all radiation safety approaches at facilities which already use top-off injection, namely APS, ESRF, SLS, and Spring-8. The work necessary to make the ALS safe during top-off is 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. There has been very good progress recently, culminating in an outside peer review of the radiation safety tracking studies in April 2007, demonstrating that injection with safety

shutters open is safe given certain controls with interlock systems and verification of apertures.

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. Additional shielding was added to that one beamline and regulatory approval was received for the studies. Radiation levels found with large missteering of the injected beam were acceptable. Aperture defining collimators installed in locations away from beamline source points minimized the radiation levels further.

These collimators are also effective at localizing beam losses due to Touschek scattering as well as beam trips. Local shielding will be added later to the collimator locations. Overall, the measurements carried out so far indicate that the routine radiation dose rate on the user floor will be lower in top-off operation, despite the higher beam currents and shorter lifetimes. At the same time, they protect permanent magnet insertion devices from radiation damage.

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. Since it is impossible to demonstrate experimentally that the accident scenario cannot happen, we followed the approach of other facilities (APS, ESRF, ...) to demonstrate the safety of top-off injection with tracking studies. For the tracking studies, a new tracking routine was implemented, since no codes were available that included all necessary effects [5].

Fig. 3 shows the result of backtracking studies for one ALS beamline. Challenges in the tracking are the unusual (very large) oscillation amplitudes of the particles as well as the extremely large number of parameter combinations and initial phase space conditions one has to study. As a result of the tracking studies one can come up with a set of controls that ensure top-off injection are safe. The necessary controls we plan to use are mostly similar to other facilities. They consist of several interlock systems, that only allow injection with beamline shutters open, if there is stored beam in the storage ring, the beam energy of the booster is very close to the storage ring, several storage ring magnets are close enough to their nominal settings, as well as regular alignment surveys of important apertures in the storage ring and beamline frontends.

We plan to continue the process to receive regulatory approval for top-off operation from the Department of Energy this summer. We hope to receive approval this fall and plan to start top-off operation before the end of the year.

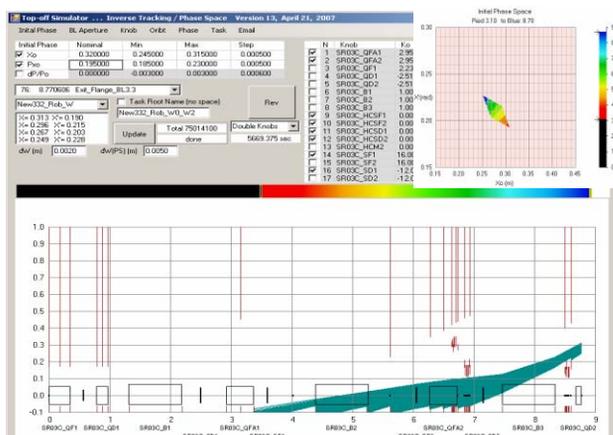


Figure 3: Backwards tracking studies for beamline 3.3.2. Particle traces are shown for varying many lattice and magnet failure parameters by about 10 steps each.

INJECTION EFFICIENCY AND EFFECTS OF INSERTION DEVICES

Although top-off is effective in allowing to operate with shorter lifetimes (smaller emittances) and therefore somewhat reduces the importance of the dynamic momentum aperture in terms of the lifetime, the nonlinear transverse single particle dynamics remains very important. The reason is that because of radiation background issues, the injection efficiency needs to remain high. In recent years it has been realized that particularly at relatively low energy light sources like the ALS the effects of insertion devices on the beam dynamics can be very large. For the ALS the effects of so-called dynamic field integrals due to the intrinsic transverse field roll-off of APPLE-II type undulators turned out to be strong enough to significantly affect injection efficiency. The newest 90 mm period MERLIN EPU would have prevented any injection without corrective measures. A shimming technique first proposed at ESRF a few years ago can be fairly efficient in compensating the dynamic field integrals with static ones of opposite sign.

During the last year, all three existing 50 mm period EPU's at the ALS were shimmed successfully in situ. The results agreed with simulations and after the shimming the impact of the EPU's on the dynamic momentum aperture was dramatically reduced (Touschek lifetime reduction of up to 20% before shimming, no measurable effect after shimming). This improvement will allow top-off injection with high (>90%) injection efficiency independent of the settings of EPU's. Fig. 4 shows the measured reduction in the sum of the dynamic and (compensating) static field integrals. Particularly the nonlinearity of the kick the beam experiences for amplitudes larger than 3 mm was reduced significantly.

Another injection efficiency problem relevant for top-off that was recently understood was an originally observed drop in injection efficiency to about 50% when closing the straight section physical aperture to 5 mm (full aperture). Further studies showed that the main effect was that the ver-

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EPU: measured sum of static and dynamic field integrals

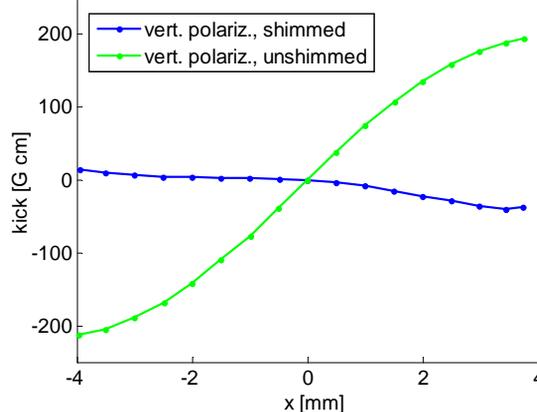


Figure 4: Sum of dynamic and static field integrals without and with shims.

tical emittance of the beam extracted from the booster was too large. Careful control of the tune at extraction to stay far away from any coupling resonances solved the problem, resulting in an injection efficiency of >90% even with 5mm vertical physical aperture.

CONCLUSIONS

The top-off upgrade of the ALS is well underway. All major hardware has been installed and commissioned. Remaining tasks include the troubleshooting of the largest new booster power supply, which is currently used in a partial configuration not allowing full energy injection, as well as the completion of the radiation safety studies leading to regulatory approval and the installation of the last remaining interlock systems. The plan is to move to full energy injection within the next few months, receive regulatory approval in fall and start full top-off operation before the end of the year. Along the way, interesting problems have been solved to enable top-off injection with high injection efficiency, mostly associated with the effects of APPLE-II type undulators on the transverse beam dynamics. The result of the top-off upgrade will be a significant improvement in brightness for ALS users, keeping the ALS fully competitive with newer light sources.

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