STATUS OF THE ALS BRIGHTNESS UPGRADE*

C. Steier†, B. Bailey, A. Biocca, A. Black, D. Colomb, N. Li,
A. Madur, S. Marks, H. Nishimura, C. Pappas, S. Prestemon, D. Robin, S. Rossi,
T. Scarvie, R. Schlueter, C. Sun, W. Wan, LBNL, Berkeley, CA 94720, USA

Abstract

The Advanced Light Source (ALS) at Berkeley Lab while one of the earliest 3rd generation light sources remains one of the brightest sources for soft x-rays worldwide. A multiyear upgrade of the ALS is currently under way, which includes new and replacement x-ray beamlines, a replacement of many of the original insertion devices and many upgrades to the accelerator. The accelerator upgrade that affects the ALS performance most directly is the ALS brightness upgrade, which will reduce the horizontal emittance from 6.3 to 2.2 nm (2.6 nm effective). This will result in a brightness increase by a factor of three for bend-magnet beamlines and at least a factor of two for insertion device beamlines. Magnets for this upgrade are currently in production and will be installed starting later this year.

INTRODUCTION

The ALS produces light over a wide spectral range for users from far infrared (IR) to hard x rays with the core spectral region in the ultraviolet (UV) and soft x-rays region. In this core region (relevant to life-science, chemistry, catalysis, surface science, nanoscience, and complex materials), the ALS remains competitive with the newest synchrotron radiation sources worldwide. The quality of the science program is directly connected to the performance of the accelerator complex and therefore continued upgrade of the accelerator are a core part of the ALS strategic plan. The main accelerator component of the ALS upgrades is the brightness upgrade that is described in detail in this paper.

BRIGHTNESS UPGRADE

Over the years, the brightness of the ALS has been steadily improved, keeping track with newer light sources and keeping the ALS the brightest third generation light source in the energy range below 1 keV. The upgrades included improvements in beam parameters (current and emittance), addition of new radiation producing devices (Superbends and advanced insertion devices) as well as stability improvements going hand-in-hand with the brightness improvements. The last upgrade was the migration to top-off operation completed in 2009.

The low emittance upgrade as described in this paper will increase the brightness at the ALS by about a factor three in the bending magnet beamlines, and by about a factor two in the existing insertion device beamlines. The upgrade also opens the door to a potential further increase of the ALS brightness in a future ”ultimate” upgrade allowing lattices with smaller horizontal beta functions in the insertion device straights and higher brightness.

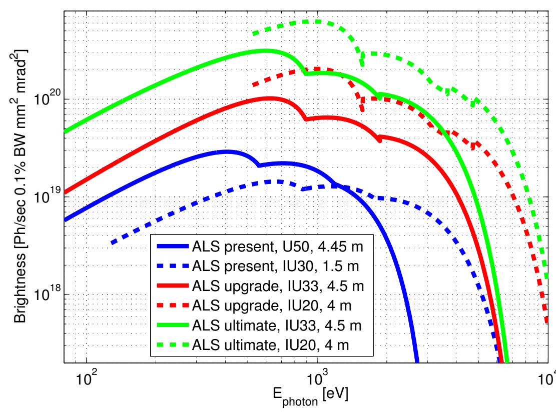

Figure 1: Comparison of the current ALS brightness around 1 keV (i.e. after top-off upgrade) with future brightness after the low emittance upgrade (as well as a more speculative case, if low horizontal beta function lattices are workable).

Lattice Choice and Options

The ALS lattice is a triple bend achromat structure, with a fixed, large defocusing gradient in the bending magnets. Originally, there were only 2 families of sextupoles, with 4 sextupoles in each arc. To understand the potential of the ALS magnet arrangement, multiple techniques were employed. At first, lattices close to the nominal lattice were studied [1]. An attractive set of possible lattices was found with a straight section dispersion of $\eta_x = 12 - 15$ cm and an integer tune two units higher than the current lattice ($\nu_x = 16.25$ instead of 14.25). Those lattice have natural emittances of just above 2 nm (compared to the more than 6 nm of the current lattice).

Later on, more systematic techniques [2, 3, 4] were used to find the global optimal lattices in terms of emittance or brightness including the use of multi-onjective genetic algorithms to simultaneously optimize linear and nonlinear properties of the lattice. These studies confirmed the lattices found earlier were already optimal in terms of emittance, but there is an additional family of low emittance lattices with very small horizontal beta function (order of 0.5

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† CSteier@lbl.gov

m) in the straights at much higher phase advance, which increase the brightness by better matching to the photon diffraction ellipse, which we continue to investigate.

The high-beta baseline lattices are within the range of the existing quadrupole magnets and power supplies. However, the sextupoles would not be strong enough and the dynamic aperture would be very poor. Both challenges are overcome with the addition of moderately strong sextupoles in the straight sections.

Scope of Upgrade

In total 48 new magnets will be installed. Because the ALS is already a fairly congested ring with many user beamlines, this is not an easy undertaking. The new magnets replace 46 existing dipole corrector magnets, which are used in slow and fast orbit feedback, as well as insertion device feed-forward, so the new magnets will have to take over these functions. There are also many space restrictions due to accelerator components or user beamlines. Therefore, we ended up with three optimized magnet designs (with 22, 2, and 24 magnets). Images of the first article magnets of all three designs can be seen in Fig. 2.

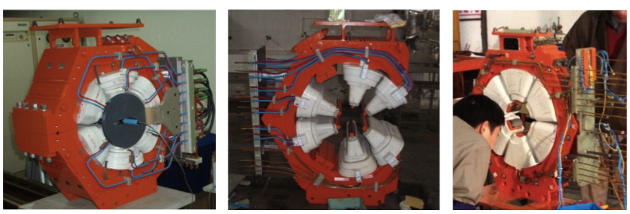

Figure 2: First article magnets of the three different types of magnets. Left: Straight section magnet; Middle: Arc magnet; Right: Special injection straight magnet.

One of the families is optimized for small hysteresis and fast time response and has a closed yoke. It will be used as primary correctors in fast orbit feedback. All new sextupoles also contain skew quadrupole coils (even though only half of them will be connected topower supplies initially). Based on detailed simulations we expect that this will allow us to improve the vertical beamsize stability in the ALS by allowing an effective correction of the relatively small skew quadrupole errors of the planar insertion devices.

Magnet Production Status

The magnet designs were refined, reviewed and a first technical prototype was completed early in 2011. The magnet performance in general agreed with expectations and production of the first article magnets started in March 2011.

Full magnet production, carried out by SINAP, is now well underway. All first article magnets were completed late last year and early this year and more than half of the production magnets have been shipped. Magnetic performance closely agrees with the design expectations and production quality of the latest magnets is excellent. Completion of the final batch of magnets is expected in July. Some individual magnets will be (test) installed this summer with the balance installed in the next major ALS shutdown in January next year.

Lattice Performance

The upgrade lattices found with the techniques listed above are generally very robust even when including insertion device effects. Fig. 3 shows an off-energy frequency map for the baseline lattice of the upgrade, including lattice errors and physical apertures. The dynamic and momentum aperture is more than sufficient for good injection and good lifetime and in fact larger than for the present ALS lattice.

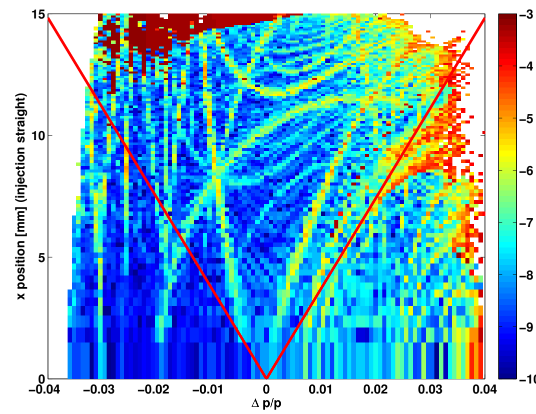

Figure 3: Example of an optimized offenergy frequency map for the baseline lattice (including magnet errors and physical apertures)

We also studied effects of all existing insertion devices, using RADIA kick-maps including all effects of dynamic multipoles. Because of the larger horizontal beta functions, these could in principle have larger impact, however, we found that the impact both on and off-energy is acceptable. Finally we calculated expected Touschek lifetimes. Fig. 4 shows the calculated momentum aperture of the upgrade lattice, including all lattice errors and physical apertures. Despite the smaller emittances, the predicted Touschek lifetime is larger than for the current lattice, because of the larger dynamic momentum aperture and the larger RF bucket size resulting from the smaller momentum compaction factor.

Other Project Activities

In order to allow enough space in all locations where new magnets are going to be installed, several modifications of vacuum chambers and stands have already been completed (including flexband assemblies in the injection straight). Power supplies for the new magnets have been tested and qualified and are now in production. Control system interfacing for all new power supplies is complete. Because of the new magnets and new magnet strengths, parts of the safety analysis (reverse tracking) for top-off

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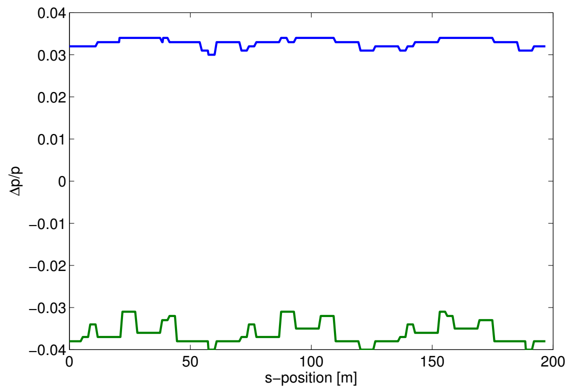

Figure 4: Calculated momentum aperture of the upgrade lattice including fs-slicing insertion.

operation needed to be redone. The analysis is almost complete (see an example of a back-tracked trajectory in Fig. 5) and so far only one aperture has been found that needs an easy modification that will be implemented when the magnets are installed.

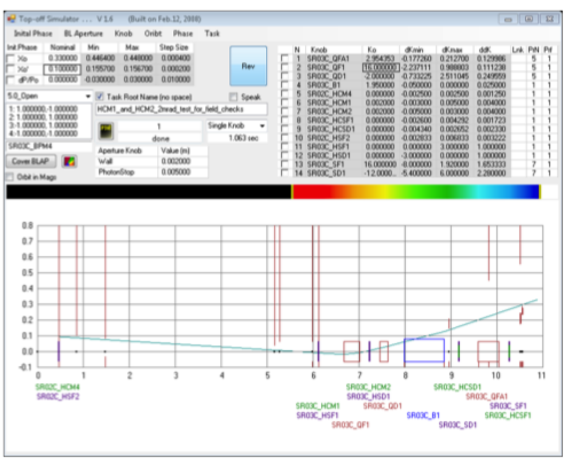

Figure 5: Example trajectory from the topoff safety backtracking.

For the fs-slicing facility, the ALS has a complex lattice insertion that manipulates the local coupling and vertical dispersion to spatially separate the sliced beam. The new lattices required a completely new solution making use of the additional skew quadrupoles added to the new SHF magnets just adjacent to the insertion devices. The solution was found using genetic algorithms [5] and its lattice functions are shown in Fig. 6. Dynamic aperture and momentum aperture including the fs-slicing lattice insertion are similar to the bare lattice.

Beyond the baseline of the project, which is aimed at delivering higher brightness, work is also going on to study low alpha modes of operation, which are enabled by the fact that the new sextupoles allow control of the second order momentum compaction factor. We also continue to study the more speculative low beta lattices including lattices with alternating high and low beta functions. Multi parameter simultaneous optimization of the linear and nonlinear lattice with genetic algorithms is used as a tool [6].

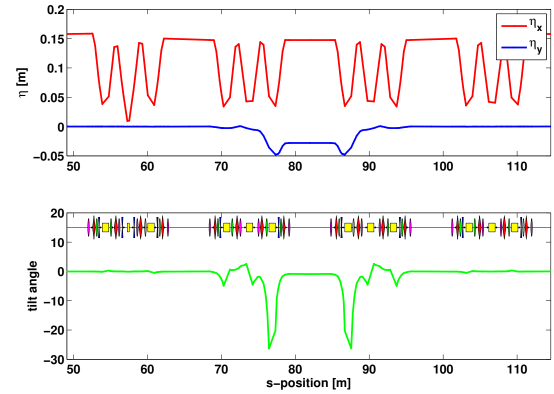

Figure 6: New fs-slicing optics that provides the spatial separation of the energy sliced beam in the new upgrade lattices.

SUMMARY

An upgrade project is under way to further improve the brightness of the ALS by reducing the horizontal emittance from 6.3 to 2.2 nm. This will result in a brightness increase by a factor of 3 for bend magnet beamlines and at least a factor of 2 for insertion device beamlines. After the upgrade is completed early next year, the ALS will have one of the smallest horizontal emittances of all operating 3rd generation light sources. Magnet production is progressing well, power supplies are in procurement and installation is going to start later this summer. Installation will be finished in the next ALS shutdown in January 2013.

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