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Authors
Steier, C
Madur, A
Bailey, B
et al.

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COMPLETION OF THE BRIGHTNESS UPGRADE OF THE ALS*

C. Steier†, A. Madur, B. Bailey, K. Berg, A. Biocca, A. Black, P. Casey, D. Colomb, B. Gunion, N. Li, S. Marks, H. Nishimura, C. Pappas, K. Petermann, G. Portmann, S. Prestemon, A. Rawlins, D. Robin, S. Rossi, T. Scarvie, R. Schlueter, C. Sun, H. Tarwaneh, W. Wan, E. Williams, LBNL, Berkeley, CA 94720, USA
L. Yin, Q. Zhou, J. Jin, J. Zhang, C. Chen, Y. Wen, J. Wu, SINAP, Shanghai, China

Abstract

The Advanced Light Source (ALS) at Berkeley Lab remains one of the brightest sources for soft x-rays worldwide. A multiyear upgrade of the ALS is underway, 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 reduced the horizontal emittance from 6.3 to 2.0 nm (2.5 nm effective). Magnets for this upgrade were installed starting in 2012 followed by a transition to user operations with 2.0 nm emittance in spring 2013.

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. 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 (see Fig. 1). The quality of the science program is directly connected to the performance of the accelerator complex and therefore continued upgrades of the accelerator are a core part of the ALS strategic plan.

BRIGHTNESS UPGRADE

Over the years, the brightness of the ALS has been steadily improved, 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 recent low emittance upgrade increased the brightness of 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 brightness by potentially implementing reduced horizontal beta functions in some straights.

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† CSteier@lbl.gov

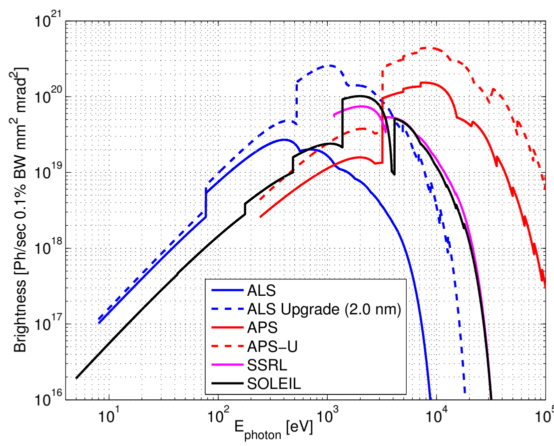

Figure 1: Comparison of ALS brightness after top-off upgrade with the current brightness after the low emittance upgrade and several other existing light sources.

Upgrade Lattice

The ALS lattice has 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. An attractive set of possible upgrade lattices was found with higher straight section dispersion and an integer tune two units higher than the old lattice [1]. Those lattices have natural emittances of just above 2 nm (compared to the more than 6 nm of the old lattice).

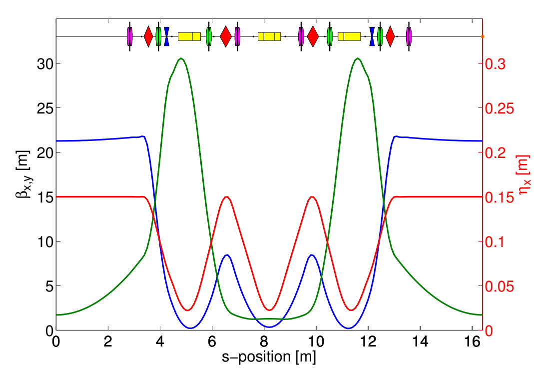

Figure 2: ALS upgrade lattice with 2.0 nm natural emittance at 1.9 GeV.

Later on, more systematic techniques [2, 3, 4] were used to find the global optimal lattices in terms of emittance or brightness. In those studies an additional family of low

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emittance lattices was found with very small horizontal beta function (order of 0.5 m) in the straights at much higher phase advance, which increase the brightness by better matching to the photon diffraction ellipse. Such lowe beta straights are still under investigation as an insertion for selected straights.

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

Magnet Design and Production

The design [5] of the new sextupoles was performed in a collaboration by LBNL and SINAP and was finished in 2011. Because of space constraints, 3 different magnet designs are used. One of the families is optimized for small hysteresis and fast time response and has a closed yoke. It is used as the primary correctors in the fast orbit feedback. All new sextupoles also contain skew quadrupole coils (half of them have been initially connected to power supplies). This allows to improve the vertical beamsize stability in the ALS by providing an effective correction of the relatively small skew quadrupole errors of the planar insertion devices. Some of the skew quadrupoles in three of the ALS arcs are also necessary to provide the vertical dispersion bump for the fs-slicing facility in the upgrade lattice.

Magnet production, carried out at SINAP (see Fig. 3), started with prototype magnets just after the design reviews in early 2011. The pole shapes were manufactured by wire edm on fully assembled magnet cores to achieve excellent field quality. Manufacturing was completed in summer 2012, on time to achieve the project installation milestones. During construction there was a detailed quality assurance program and all magnets were fully qualified by electrical, mechanical, and magnetic measurements. Precise fiducialization was carried out both mechanically and with the help of magnetic measurements. All magnets exceeded all important field quality requirements.

Figure 3: Assembly of magnets at SINAP.

Other Project Activities

In order to create sufficient space in all locations where new magnets were going to be installed, several modifications of vacuum chambers and stands were completed in 2012. Several candidate power supplies for the new magnets were tested and the control system interfaces for the selected power supplies were completed. Because of the new magnets and new strengths of existing interlocked magnets, parts of the safety analysis for top-off operation needed to be redone. The analysis was completed in time for the installation shutdown and no hardware changes were necessary. The new analysis allowed to widen the interlock ranges on many of the top-off interlocked magnets allowing wide flexibility with the new lattices.

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 [6] and its lattice functions are shown in Fig. 4.

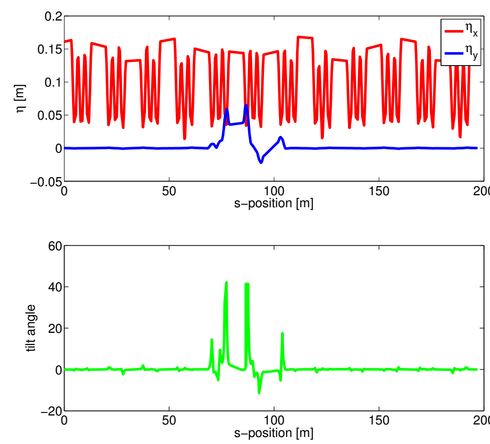

Figure 4: New fs-slicing optics that provides the spatial separation of the energy sliced beam in the new upgrade lattices.

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.

Installation

After installing 13 of the new sextupoles ahead of time, fully testing their corrector functionality (time response, hysteresis) and incorporating them into slow and fast orbit feedback, the remainder of the 48 magnets were installed during the 2013 spring shutdown (see Fig. 5). At the same time, all new power supplies and equipment protection systems were installed and the topoff interlock ranges enlarged and the interlocks retested.

COMMISSIONING

Simulations beforehand had predicted excellent dynamic and momentum aperture as well as lifetime for the opti-

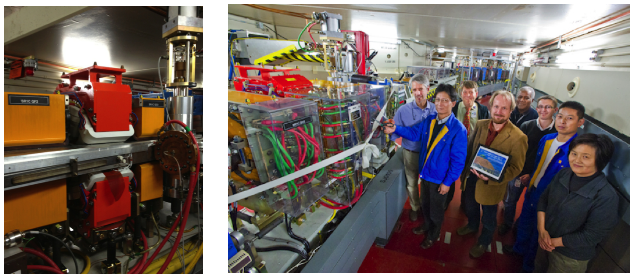

Figure 5: Left: SHD magnet installed between the QF and QD quadrupoles. Right: Ribbon curring celebration after successful installation.

mized upgrade lattices [4, 7]. Figure 6 shows an off-energy frequency map for the baseline lattice of the upgrade, including lattice errors and physical apertures.

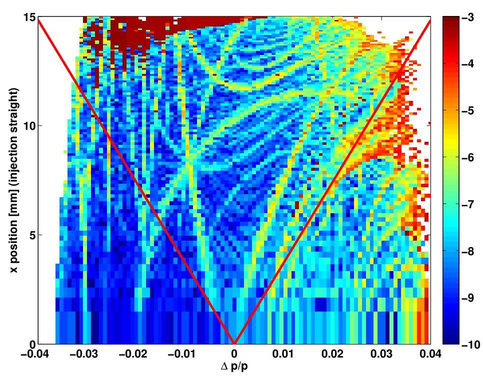

Figure 6: Example of an optimized offenergy frequency map for the baseline lattice (including magnet errors and physical apertures)

Migration to the new lattices was quick (few hours), after verifying all magnet polarities and magnet transfer functions in a beam based way in the old lattice. Further commissioning included optimizing the harmonic sextupole settings, updating the ID feed-forward (tune, beta beating, coupling) for the new lattice, implementing the new dispersion bump for fs-slicing facility and retesting the top-off interlocks with new ranges. The dispersion bump was refined after final lattice optimizations. The dynamic aperture and momentum aperture including the fs-slicing lattice insertion are similar to the bare lattice results and commissioning of the new solution went quickly. The new lattices also provide a larger, intrinsic horizontal separation of the sliced electron beam. We are currently in the process of evaluating how to make best use of this and expect that it will eventually allow a much better signal to noise ratio for the slicing facility.

Optimizing photon beamlines with new beam spots progressed quickly and user beamlines were able to resolve the brightness increase (see Fig. 7). The dynamic aperture and momentum aperture for the upgrade lattice were confirmed to be very close to the expected ones and the Touschek beam lifetime after the upgrade, despite the smaller horizontal and slightly smaller vertical emittance, as predicted is larger than before the upgrade, due to the larger dynamic momentum aperture.

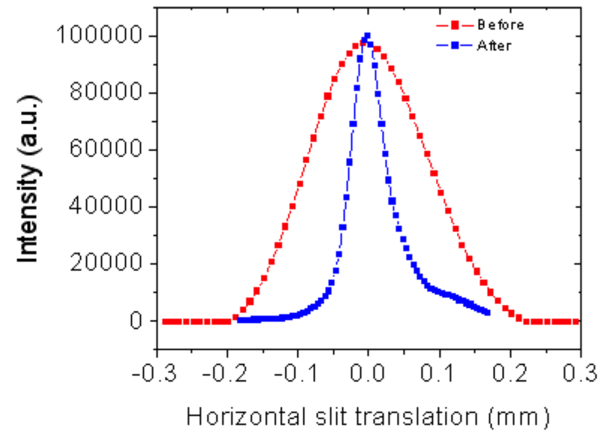

Figure 7: Comparison of the horizontal beam profile before and after the upgrade measured at one user beamline showing the factor of three improvement in brightness (vertical scale is renormalized).

SUMMARY

An upgrade project has been completed improving the brightness of the ALS by reducing the horizontal emittance from 6.3 to 2.0 nm. This resulted in a brightness increase by a factor of three for bend magnet beamlines and at least a factor of two for insertion device beamlines. The ALS now has one of the smallest horizontal emittance of all operating 3rd generation light sources. Initial user operations has been very successful. Most beamlines have been able to benefit significantly from the upgrade. No interruptions during the first month of user operations related to the upgrade.

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