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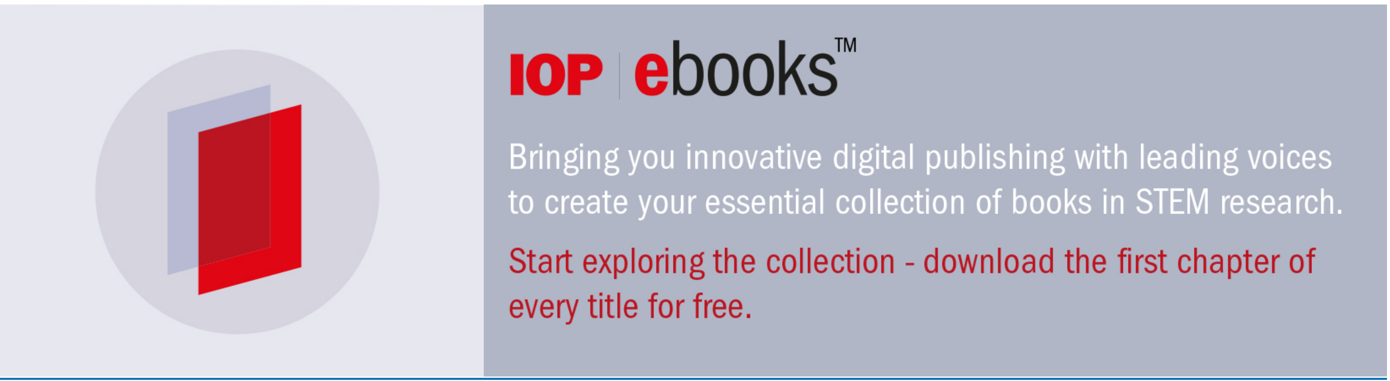

Completion of the Brightness Upgrade of the ALS∗

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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 [1], which reduces the horizontal emittance from 6.3 to 2.0 nm (2.5 nm effective). Magnets for this upgrade were installed in late 2012 and early 2013 followed by user operation with the reduced emittance.

1. 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 being soft x-rays. In this core region (relevant to life-science, chemistry, catalysis, surface science, nano-science, and complex materials), the ALS remains competitive with the newest synchrotron radiation sources worldwide (see brightness comparison in Fig. 1).

2. Brightness Upgrade Lattice Design

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 sextupole magnets 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 [2]. Those lattices have natural emittances of just above 2 nm (compared to the more than 6 nm of the old lattice). Later on, more systematic techniques [1, 3, 4] were used to find the global optimal lattices in terms of emittance or brightness. In those studies an additional family of low 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 low-beta insertions are still under investigation for selected straights.

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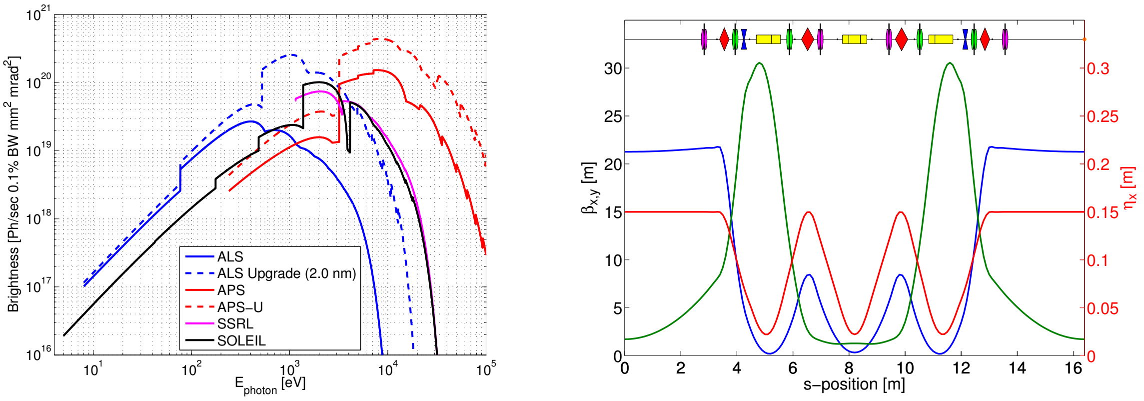

Figure 1. Left: Comparison of ALS brightness before and after the brightess upgrade with several other existing light sources. Right: Lattice functions of ALS upgrade lattice with 2.0 nm natural emittance (1.9 GeV).

The high-beta lattices are within the range of the existing quadrupole magnets. However, the original sextupoles were too weak and the dynamic aperture would have been very poor. Both challenges were overcome with the addition of sextupoles in the straight sections.

With the addition of new magnets and the changed strength 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.

3. 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 sextupole magnet designs are used. One of the families is optimized for small hysteresis and fast time response and has a closed yoke. It is also used as primary correctors in the fast orbit feedback. All new sextupoles also contain skew quadrupole coils (half of them are currently connected to power supplies). This allows to improve the vertical beamsize stability in the ALS by providing an effective correction of the small but relevant skew quadrupole errors of the planar insertion devices.

Magnet production, carried out at SINAP, 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 the necessary field quality requirements.

4. Installation

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. The installation started late in 2012 during short maintenance shutdowns, with 13 of the new sextupoles being installed ahead of the main installation shutdown. This allowed to test their corrector functionality (time response, hysteresis) and to incorporate them into slow and fast orbit feedback. The remainder of the 48 magnets were installed during the 2013 spring shutdown (see photos in Fig. 2). At the same time, all new power supplies and equipment protection systems were installed, the topoff interlock ranges enlarged and the interlocks retested.

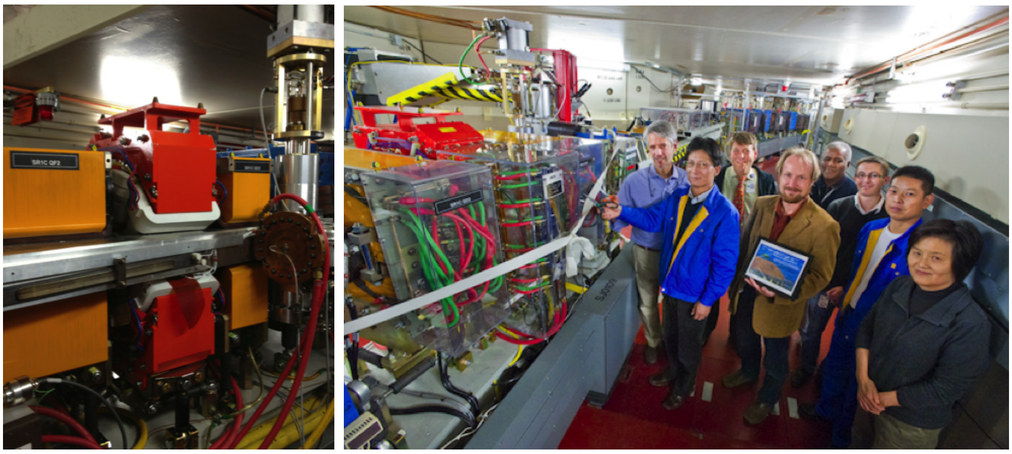

Figure 2. Left: SHD magnet installed between two of the QF and QD quadrupoles. Right: Ribbon cutting celebration after successful installation.

5. Commissioning

Migration to the new lattices was quick (few hours), after all magnet polarities and magnet transfer functions had been verified in a beam based way in the old lattice. Simulations had predicted excellent dynamic and momentum aperture as well as lifetime for the optimized upgrade lattices [1, 7]. These predictions were quickly confirmed. Further commissioning included optimizing the harmonic sextupole settings, updating the ID feed-forward algorithms (tune, beta beating, coupling) for the new lattice, implementing the new dispersion bump [6] (see Fig. 3) for the fs-slicing facility and retesting the top-off interlocks with new ranges.

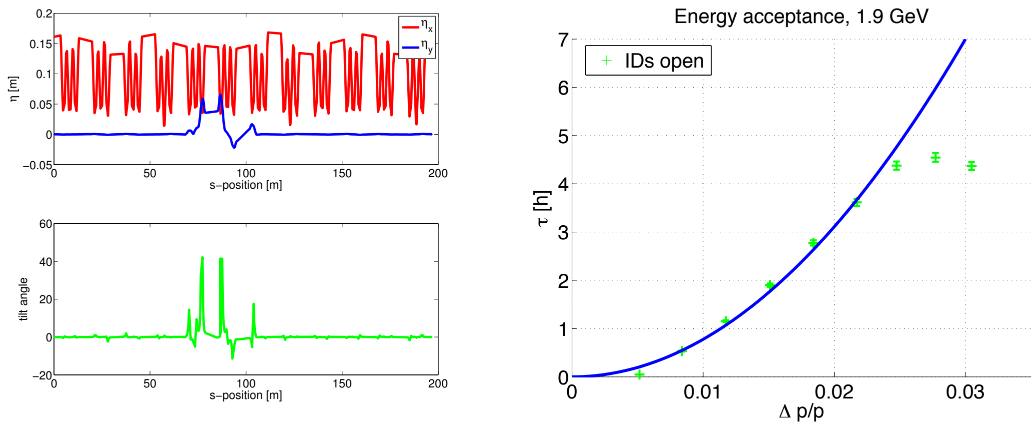

Figure 3. Left: New fs-slicing optics that provides the spatial separation of the energy sliced beam in the new upgrade lattices. Right: Lifetime vs. RF amplitude scan for the upgrade lattice confirming improved momentum acceptance compared to operation before the upgrade.

The dispersion bump was refined after final lattice optimizations. The dynamic aperture and momentum aperture (see Fig. 3) including the fs-slicing lattice insertion are similar to the bare lattice results and commissioning continued on a fast pace. 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 the photon beamlines for the new beam dimensions progressed quickly and user beamlines were able to resolve the brightness increase (see Fig. 4). The Touschek beam lifetime after the upgrade, despite the smaller horizontal and slightly smaller vertical emittance is larger than before the upgrade, due to the larger dynamic momentum aperture, as predicted.

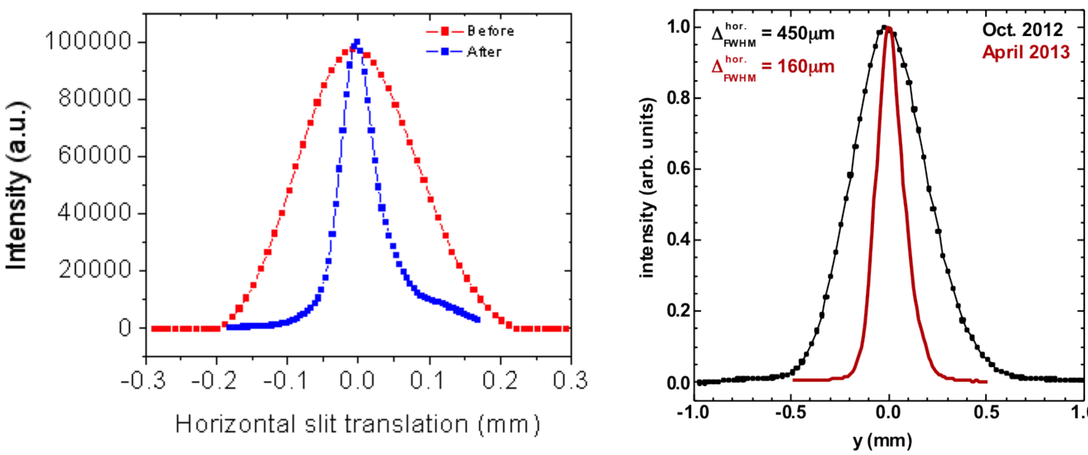

Figure 4. Comparison of the horizontal beam profile before and after the upgrade measured at beamlines 12.3.2 and 6.3.1 showing the factor of three improvement in brightness (vertical scale is renormalized, both beamlines have different magnification factors).

6. 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 emittances 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 months of user operations were related to the upgrade.

7. Acknowledgements

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