STATUS OF THE ALS UPGRADE*

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Abstract

The Advanced Light Source (ALS) at Berkeley Lab is one of the earliest 3rd generation light sources. Over the years substantial upgrades have been implemented to keep the facility at the forefront of soft x-ray sources. A multi-year upgrade 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 and will keep the ALS competitive with newer sources.

ALS STRATEGIC PLAN

As a result of an ongoing dialogue with the ALS user community about their needs, the ALS strategic plan focuses on the 2009–2016 time period and on the needs of 21^{st} century science as discussed in such documents as the Basic Energy Science (BES) Grand Challenges Report [1] and the reports issuing out of the BES Basic Research Needs Workshops. The four main components of the strategic plan are:

- New and upgraded beamlines
- Upgraded accelerator complex
- Enabling technical capabilities
- User scientific support and future scientist pipeline

In the following sections, we will focus on the accelerator upgrade components of the strategic plan and specifically the Brightness Upgrade.

Accelerator Upgrades

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 is the national leader and at the forefront of synchrotron radiations sources worldwide. The quality of the science program is directly connected to the performance of the accelerator complex. The plan for accelerator renewal is to continue with upgrades of the accelerator with the goal of remaining at the forefront of synchrotron radiation sources. The proposed upgrades fall into five categories:

- Higher horizontal brightness: It is possible with moderate lattice upgrades to double the horizontal brightness in the insertion device beamlines, as well as a tripling of the brightness in the Superbend and central bend magnet beamlines (compare Fig. 1).
- New Storage ring operational modes: This includes quasi-single bunch operation [2] by using a revolution frequency synchronous fast kicker magnet, as well as the possibility to operate with short bunches at reduced current, to deliver enhanced THz radiation, as well x-ray pulses of low intensity with few ps duration.
- Improved photon beam stability and control: Targeted upgrades in controls and diagnostics will provide state-of-the-art beam stability.
- Enhanced reliability of the accelerator complex: A number of equipment upgrades and replacement of ageing critical systems are under way. This includes the RF amplifiers [3], parts of the control system [4], some power supplies, as well as upgrades to the low conductivity water system.
- New insertion device R&D: The plan is to continue the innovative effort for carrying out R&D for EPUs and/or improved field shapes as well as superconducting undulators [5] for achieving ultimate brightness in the soft x-ray range.

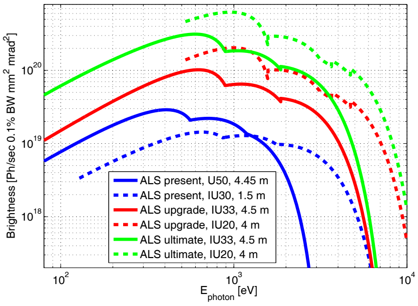

Figure 1: Comparison of the current ALS brightness around 1 keV (i.e. after top-off upgrade) with future brightness after the low emittance upgrade (as well as a more speculative case, if low horizontal beta function lattices are workable).

Many of the upgrades are well underway and are described elsewhere. In the following, this paper will concentrate on the brightness upgrade, which also will enable the operation with small momentum compaction factors

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* Work supported by the U.S. Department of Energy under Contract No. DE-AC02-05CH11231

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by providing control of the second order momentum compaction factor.

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 even further increase of the ALS brightness in a future ”ultimate” upgrade allowing lattices with small horizontal beta functions in the insertion device straights and much higher brightness because of the better match of the electron phase space to the photon diffraction ellipse. This ultimate upgrade is under study and would require further changes to the accelerator.

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 [6]. 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) and despite the fairly sizeable dispersion in the straights, the effective emittance is small as well (2.6 nm).

Later on, more systematic techniques [7, 8, 9] 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 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. The addition of moderately strong sextupoles in the straight sections allows very good dynamic (momentum) apertures and also reduces the required strength for the chromatic sextupoles to achievable values.

Scope of Upgrade

- Replace existing corrector magnets with combined sextupole/corrector/skew quadrupole multimagnets
- Implement new low emittance lattices enabled by the addition of the harmonic sextupoles
- New power supplies, controls for the new magnets
- Magnetic measurements, fiducialization, EPS systems, installation
- Top-off qualification of all new lattices
- Transition with minimum negative impact (orbit feedbacks, commissioning time, teething period)

In total 48 new magnets will be installed. Because the ALS is already a fairly congested ring with many (more than 40) 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 different magnet designs (with 22, 2, and 24 magnets). Models of the final magnet designs can be seen in Fig. 2.

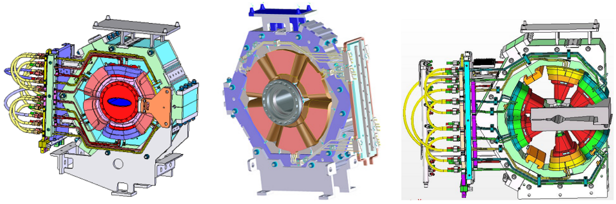

Figure 2: 3D CAD models of the detailed designs for the three different types of magnets. Left: Straight section magnet; Middle: Special injection straight magnet; Right: Arc magnet.

One of the families is optimized for small effects due to saturation, small hysteresis and fast time response and has a closed yoke. It will be used as primary correctors in orbit feedback. Because of the relatively large pole tip radius and the relatively weak sextupole strength, the multipole components found in the magnetic simulations (including machining errors, saturation, 3D effects) presented no problems for the beam dynamics. The magnet designs were refined, reviewed and a first technical prototype (see Fig. 3 was completed early in 2011. The magnet performance in general agreed with expectations and production of the first article magnets started in March 2011.

Beam Dynamics

The upgrade lattices found with the techniques listed above are generally very robust against insertion device effects. Fig. 4 shows an off-energy frequency map for the

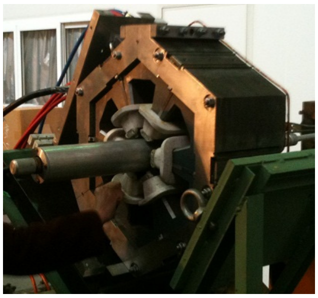

Figure 3: Photo of the first technical prototype magnet.

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.

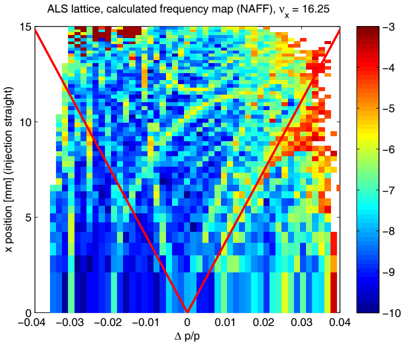

Figure 4: Example of an optimized offenergy frequency map for the baseline lattice (including magnet errors and physical apertures)

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. 5 shows the calculated Touschek lifetime 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 Challenges

In addition to the lattice and magnet design and nonlinear dynamics challenges mentioned above, there are several other challenges to the project. As already mentioned, one family of the new sextupole multimagnets will also be used in the fast orbit feedback, requiring high bandwidth and low hysteresis. Extensive measurements and simulations were carried out to minimize this risk. Other challenges include the smaller instability thresholds and shorter bunchlengths due to the smaller momentum compaction factor. Finally, the new lattices need to be qualified for top-off operations [10] requiring rerun of some simulations. Overall, the results on all of those issues are positive so far and the project successfully passed several reviews.

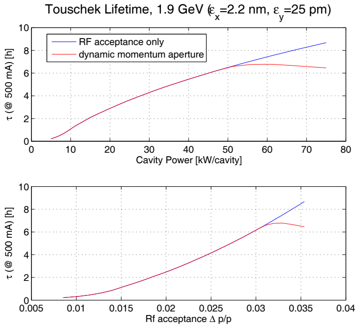

Figure 5: Calculated Touschek lifetime versus RF bucket sizes and cavity powers. Nominal operating power of the ALS cavities is about 43 kW.

Beyond the baseline of the project, which is aimed at delivering higher brightness, work continues on the study of low alpha modes as well as injection into the more speculative low beta lattices [11].

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 (2.6 nm effective emittance). 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 and will keep the ALS competitive with newer sources. All detailed magnet designs are finished and beam dynamics calculations show sufficient dynamic and momentum aperture. Magnet construction is well underway, initial prototypes perform to expectations, and magnet installation is planned for 2012.

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