STATUS OF THE CONCEPTUAL DESIGN OF ALS-U*

C. Steier†, A. Allézy, A. Anders, K. Baptiste, J. Byrd, K. Chow, G. Cutler, R. Donahue, R. Duarte, J.-Y. Jung, S. Leemann, M. Leitner, T. Luo, H. Nishimura, T. Oliver, O. Omolayo, J. Osborn, C. Pappas, S. Persichelli, M. Placidi, G. Portmann, S. Reyes, D. Robin, F. Sannibale, S. De Santis, C. Sun, C. Swenson, M. Venturini, W. Waldron, E. Wallén, W. Wan,
LBNL, Berkeley, CA 94720, USA

Abstract

The ALS-U upgrade promises to deliver diffraction limited performance throughout the soft x-ray range by lowering the horizontal emittance to about 50 pm resulting in 2-3 orders of brightness increase for soft x-rays compared to the current ALS. The design utilizes a multi bend achromat lattice with on-axis swap-out injection and an accumulator ring. One central design goal is to install and commission ALS-U within a short dark period. This paper summarizes the status of the conceptual design of the accelerator, as well as some results of the R&D program that has been ongoing for the last 3 years.

INTRODUCTION

To achieve diffraction-limited performance throughout the soft x-ray range, ALS-U pushes the limit of accelerator design. The targeted improvement in the coherent flux will be achieved in large part by a big reduction of the beam emittance. This requires a complete overhaul of the storage ring to replace the existing Triple-Bend with a Multi-Bend Achromat (MBA) lattice [1,2]. The design aims at producing round beams of approximately 50 pm rad emittance, about 40 times smaller than the horizontal emittance of the existing ALS. The baseline design is a nine-bend achromat. ALS-U received approval of Mission Need (CD-0) from DOE/BES in September 2016. Table 1 summarizes the main parameters and Figure 1 shows the nine bend achromat as well as the new accumulator ring.

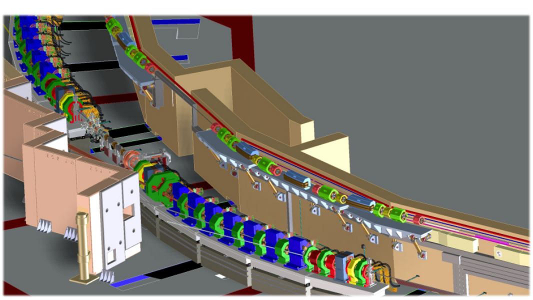

Figure 1: CAD model of ALS-U showing the existing accelerator tunnel with the new storage and accumulator rings.

Because ALS-U is a low energy machine (with strong intrabeam scattering), it requires design solutions different from those of hard x-ray projects. Therefore an R&D program was started in early FY14 at LBNL with the goal of reducing the technical risks. Based on the success of the R&D program so far, as well as the conceptual design maturation, we predict that ALS-U will provide a higher coherent flux than any other ring up to a photon energy of 3.5 keV (see Fig. 2).

Table 1: Parameter List Comparing ALS with ALS-U

Parameter	Current ALS	ALS-U
Electron energy	1.9 GeV	2.0 GeV
Beam current	500 mA	500 mA
Hor. emittance	2000 pm-rad	~50 pm-rad
Vert. emittance	30 pm-rad	~50 pm-rad
rms beam size (IDs)	251 / 9 µm	≤10 / ≤10 µm
rms beam size (bends)	40 / 7 µm	≤5 / ≤8 µm
Energy spread	9.7×10^{-4}	$\leq 9 \times 10^{-4}$
bunch length (FWHM)	60–70 ps (harm. cavity)	120–200 ps (harm. cavity)
Circumference	196.8 m	~196.5 m
Bend angle	10°	3.33°

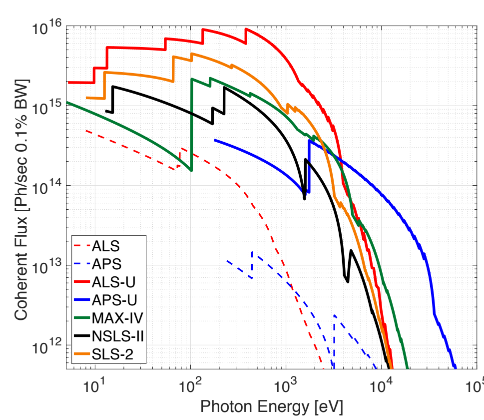

Figure 2: Coherent flux produced by selected storage-ring-based x-ray facilities.

LATTICE

Two features are required in low-emittance lattices: a large number of dipole magnets and strong focusing. These features are embodied in the MBA lattices adopted in all the new generation light-source storage rings. A systematic analysis of the lattice options indicates that M=8 or 9 bends

* This work was supported by the Director, Office of Science, Office of Basic Energy Sciences, of the U.S. Department of Energy under Contract No. DE-AC02-05CH11231.
† CSteier@lbl.gov

per arc and field gradients of about 100 T/m are needed to achieve the desired emittance.

Strong focusing adversely affects particle-orbit stability. MOGA techniques were used to optimize dynamic and momentum aperture resulting in an acceptable lifetime ($\approx$ 1 h), see Fig. 3. The adoption of frequent on-axis swap-out injection allows to optimize the lattice further and relaxes the requirement on dynamic aperture.

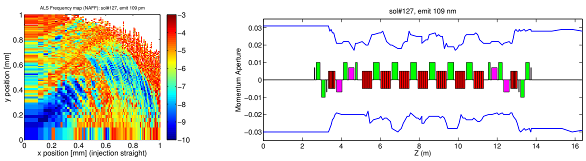

Figure 3: (Left) Frequency map for the 9BA baseline lattice with errors. (Right) Local momentum aperture for one period including errors.

Beyond the baseline lattice, work is ongoing to incorporate 3-6 Superbend magnets to retain the hard x-ray capability of the current ALS, while minimizing the impact on dynamic aperture and emittance. Currently Superbend lattices achieve similar dynamic aperture but have a slightly increased emittance compared to the baseline without Superbends. The intent is to also make use of reverse bending magnets by radially offsetting a subset of the focusing quadrupoles. This will allow to lower the emittance further, while likely maintaining similar nonlinear dynamics performance. The reverse bends also can help to mitigate the emittance effects of Superbends.

COLLECTIVE EFFECTS

Because of the narrow vacuum chamber aperture (13 to 20 mm in the arcs; as small as 4 mm in the straights) the Resistive Wall (RW) impedance is expected to be a large contributor to the overall impedance both in the longitudinal and in the transverse planes. We are developing an impedance budget and numerical models for the short-range wake functions and their effects on the beam. Preliminary results show the single-bunch instability threshold to be comfortably above the design current (see Fig. 4).

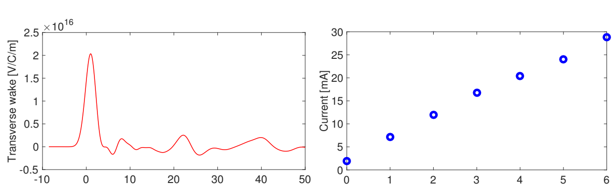

Figure 4: (Left) Total transverse wake function. (Right) TMCI threshold as a function of chromaticity.

INTRA BEAM SCATTERING

Scattering effects are stronger in low energy rings and have two consequences: they cause emittance growth (IBS) and induce particle loss. This is the main motivation for introducing harmonic cavities. Additional mitigating strategies consist of operating the machine in full-coupling mode with round beams and maximizing the occupation of the RF buckets. Thanks to these provisions, scattering effects become manageable but are still quite noticeable (see Fig. 5. Interestingly, despite the strong IBS effect, the planned operating energy of ALS-U is close to its minimum emittance (including IBS). The Touschek lifetime of the current baseline is about 1 h at 500 mA.

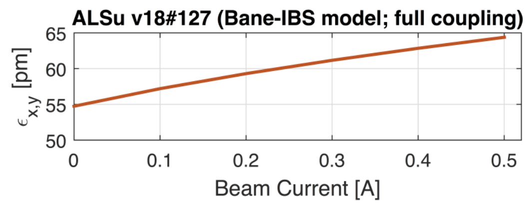

Figure 5: Emittance increase due to IBS as a function of current for nominal fill pattern, round beams, harmonic cavities, and a full set of undulators.

MAGNETS

Strong focusing in single-function quadrupoles with gradients in excess of 100 T/m and combined-function bending magnets with gradients of about 46 T/m is required to achieve the target emittance. The latter will be realized with radially off-set geometric quadrupoles; under consideration is an innovative C-shaped design with asymmetric pole-design (see Fig. 6) that promises good field quality but reduced mass and power consumption and production of an R&D demonstration magnet with this design is starting.

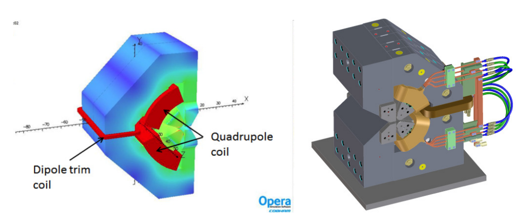

Figure 6: (Left) Field simulation for the transverse gradient dipole. (Right) CAD model of the R&D magnet which is being built to demonstrate the critical technical features of ALS-U magnets.

ACCUMULATOR AND SWAP-OUT

To optimize operation with small dynamic aperture, on axis-injection [3, 4] with bunch train swap-out and a full energy accumulator ring will be used. The new accumulator will be housed in the storage ring tunnel and will act as a damping ring. Its lattice will allow for off-axis injection from the booster and the extracted low emittance beam is injected on-axis into the small dynamic aperture of ALS-U. This allows a performance leap over rings that use stacking. The main technical challenges are the fast magnets and pulsers needed for swap-out (see Fig. 7).

ISBN 978-3-95450-182-3

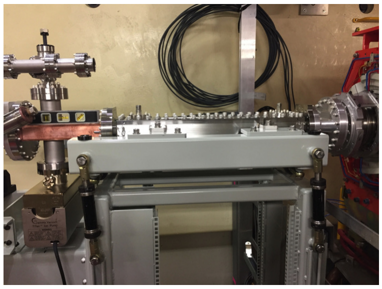

Figure 7: Stripline kicker with 6 mm full aperture between the striplines installed in the ALS.

We installed and tested a full prototype system of a small (6 mm) gap stripline kicker and an inductive voltage adder (5.5 kV) on the ALS. The stripline kicker has the same gap between its electrodes as needed for ALS-U, and was designed and built [5] in house. To allow the electrodes to handle the power deposited by wakefields via radiative cooling, a plasma deposition process was used to deposit a one micron thick (black) CuO layer. The stainless steel body was chemically treated to increase its emissivity. We also developed prototype pulser hardware and have demonstrated pulses with the necessary very short rise and fall times [6] with an inductive voltage adder. After a number of bench tests including extensive impedance and field characterization the stripline kicker was installed in the ALS in February 2017.

After installing the kicker, we first verified the electrical properties by measuring single bunch signals. Next we tested the impedance properties and high current compatibility. We operated the ALS with the kicker installed at the nominal current of 500 mA and the TMCI threshold was the same as without the kicker. Finally, we kicked the ALS beam with the stripline kicker and used turn-by-turn BPMs to measure the pulse amplitude, duration, and shape, as well as reproducibility. The results (see Fig. 8) confirm that the system fulfills the requirements for ALS-U.

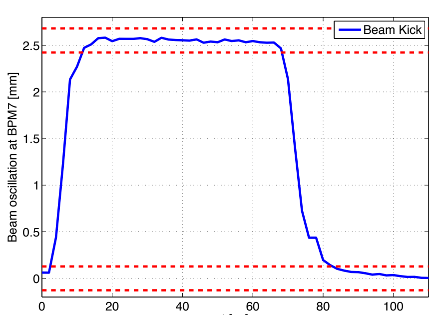

Figure 8: Beam integrated kick measured with turn-by-turn BPMs.

VACUUM

The most promising technology to achieve good vacuum pressures with the small apertures necessary are Non Evaporable Getter (NEG) coated vacuum chambers. Substantial progress has been made, both in industry, and at LBNL, bringing NEG coated chambers with less than 6 mm diameter within reach. We recently installed a first NEG coated undulator vacuum chamber in an ALS straight and are detailing the conceptual design of the photon extraction ports and arc sector chambers for ALS-U (see Fig. 9).

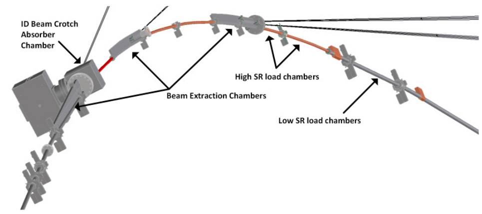

Figure 9: Conceptual layout of the arc sector vacuum chamber, photon extraction ports and absorbers.

TRANSFER LINES

An advantage of placing the accumulator in the same tunnel as the storage ring is a simplification of the layout for the transfer. Because the accumulator and storage rings have the same RF system frequency (500 MHz), the swap-out scheme requires that the path length through the two transfer lines and the path length along the accumulator between extraction and injection kickers should differ by a multiple of the RF wavelength. In addition, the usual matching conditions for the lattice functions will have to be met (see Fig. 10).

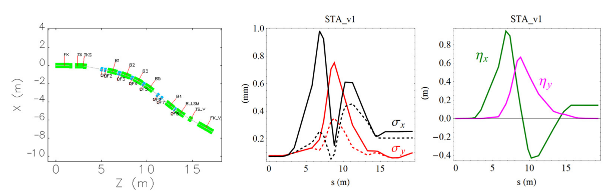

Figure 10: Layout and lattice functions of the Storage Ring to Accumulator transfer line.

SUMMARY

The conceptual design of ALS-U is progressing well promising diffraction limited performance for soft x-rays (i.e. up to 2 keV). In parallel, an R+D program to retire the main technical risks is being carried out.

REFERENCES

[1] H. Tarawneh *et al.*, *J. Phys.: Conf. Ser.* 493 012020, 2014.

[2] C. Sun *et al.*, in *Proceedings of IPAC 2016*, pp.2961, 2016.

[3] C. Steier. *Synchrotron Radiation News*, 27, 18, 2014.

[4] M. Borland, *AIP Conf Proc* 1234, 2009.

[5] S. De Santis *et al.*, in *Proceedings of IPAC2014*, p.1977, 2014.

[6] C. Steier *et al.*, in *Proceedings of IPAC2015*, p.1840, 2015.

ISBN 978-3-95450-182-3