ALS-U: A SOFT X-RAY DIFFRACTION LIMITED LIGHT SOURCE*

C. Steier†, A. Anders, J. Byrd, K. Chow, R. Duarte, J. Jung, T. Luo, H. Nishimura, T. Oliver,
J. Osborn, H. Padmore, C. Pappas, S. Persichelli, D. Robin, F. Sannibale, S. De Santis,
R. Schlueter, C. Sun, C. Swenson, M. Venturini, W. Waldron, E. Wallen, W. Wan, Y. Yang
LBNL, Berkeley, CA 94720, USA

Abstract

Improvements in brightness and coherent flux of about two orders of magnitude are possible using multi bend achromat lattice designs [1]. These improvements can be implemented as upgrades of existing facilities as in the case of the Advanced Light Source Upgrade (ALS-U). ALS-U will reuse much of the existing infrastructure, thereby reducing cost and time needed to reach full scientific productivity. This paper summarizes the accelerator design progress as well as some details of the ongoing R+D program.

INTRODUCTION

The ALS-U design replaces the existing triple-bend achromat with a stronger-focusing multi-bend achromat [2, 3] aiming at producing round beams of approximately 50 pm-rad emittance, about 40 times smaller than the horizontal emittance of the existing ALS, and thus leading to a big increase in coherent flux. The current baseline design is a nine-bend achromat. ALS-U was evaluated in June 2016 by a Basic Energy Sciences Facility Upgrade Prioritization Subcommittee as ’Absolutely Central’ to contribute to world leading science and as ’Ready to Initiate Construction’ and 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.

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°

One of the consequences of producing a small emittance is a small dynamic aperture, although the momentum acceptance will remain large enough for acceptable beam lifetime. To overcome this challenge, ALS-U will use on-axis swap-out injection to exchange bunch trains between the storage ring and an accumulator ring. Swap-out also makes it possible to employ very small, round chambers in the straight sections, enabling higher-performance undulators. ALS-U will provide a higher coherent flux than any other ring, whether in operation or planned, up to a photon energy of 3.5 keV, which covers the entire soft x-ray regime (see Fig. 2).

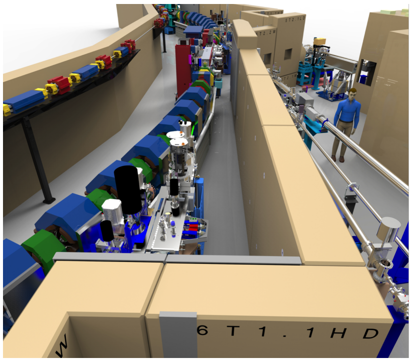

Figure 1: CAD model of ALS-U showing the existing accelerator tunnel with the new storage and accumulator rings.

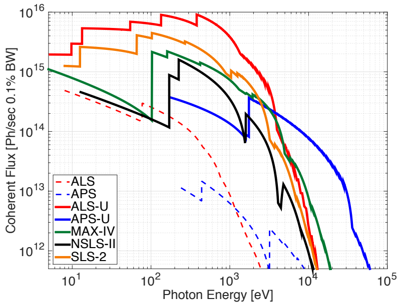

Figure 2: Coherent flux produced by selected storage-ring-based x-ray facilities.

LATTICE OPTIMIZATION

The lattice design has to balance competing goals like radiation output requirements, technological limitations, and operational demands. The most fundamental tradeoff is between small emittance and sufficient injection efficiency and lifetime. Following a now-common trend, we have been employing multi objective genetic algorithms to simultaneously optimize the linear and non-linear lattice for the lattice design. The new ALS-U ring will have the same periodic-

---

* 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

ity (12 cells) and nearly the same circumference. In each cell, bending is distributed among nine transverse-gradient dipoles [2, 3] (see Fig. 3).

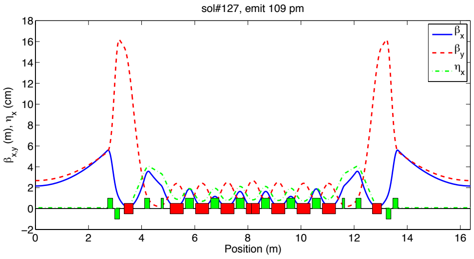

Figure 3: Lattice functions of one period of the ALS-U nine bend achromat.

The nominal tunes are close to the coupling resonance to equipartition the emittance. This has two benefits: it provides for optimal (round) cross section at the undulators and reduces scattering effects (IBS, Touschek). The dynamic aperture, on the order of 1 mm, is adequate for on-axis injection (see Fig. 4). The momentum aperture is good at up to 3%. The resulting estimate for the beam lifetime, about 0.7 h, is acceptable and the current will be kept almost constant by swap out injection.

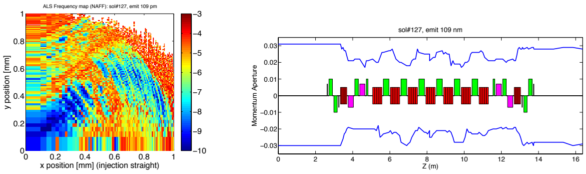

Figure 4: (Left) Frequency map (dynamic aperture) of ALS-U baseline lattice, (Right) dynamic momentum aperture, both with gradient and skew gradient errors.

Impedance and Instabilities

Reduced vacuum-chamber apertures are a key feature enabling low-emittance machines but also result in lower instability thresholds, since the impedance gets larger. The resistive wall (RW) impedance is expected to be particularly important, as a result of the small gaps in the undulators. A preliminary broadband impedance model has been completed [4]. To mitigate RW effects, we are using copper or aluminum for most of the vacuum chambers. Ensuring good vacuum will require NEG coatings which also affect the impedance. We have carried out preliminary estimates of the transverse mode-coupling instability (TMCI) threshold (see Fig. 5). In the absence of harmonic cavities these show an instability threshold at a bunch current of about I_b = 4.5 mA (nominal I_b = 1.8 mA).

In terms of multibunch instabilities, we expect no change compared to ALS in the longitudinal plane, whereas the transverse impedances will increase. However, based on initial estimates we expect that dedicated multibunch feedback systems as in the current ALS will provide sufficient damping.

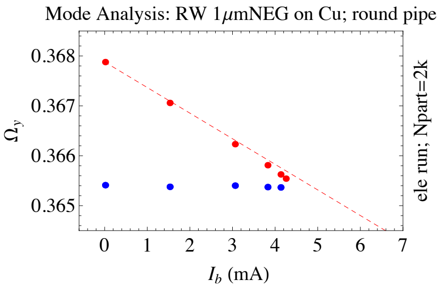

Figure 5: Effect of the RW impedance on the single-bunch transverse motion for vanishing chromaticities: the instability threshold is at $I_b \approx 4.5$ mA.

ALS-U R+D PROGRAM

To reduce technical risks, a research and development program was started at the beginning of FY14. The program concentrates on the areas with the highest technical risk or opportunity for a soft x-ray DLSR [5] and includes multiple accelerator as well as beamline R+D topics.

Magnets and Undulators

To achieve diffraction-limited emittances, quadrupole gradients on the order of 100 T/m are necessary. Pre-conceptual designs have been finished for all magnets. The magnets are all feasible; however, some of them require special materials or advanced design features to fit with the vacuum system and achieve sufficient field quality.

The smaller vertical apertures present a new opportunity, and even more importantly, equally small horizontal apertures enables undulator technologies with superior performance, especially for experiments requiring polarization control. The current plan for some of the new undulators includes devices such as Delta undulators or bifilar helical superconducting undulators.

The ALS makes extensive use of bending-magnet and superbend sources in addition to undulator sources, which need to be maintained on ALS-U. Superconducting magnets can be built small enough to fit together with two additional quadrupoles into the slot of one transverse-gradient dipole in a few locations. The field at the source points would be similar to the current ALS.

On-axis Swap-out Injection

It is planned to use on-axis injection [5,6] with bunch train swap-out and an accumulator ring. The new accumulator will be housed in the storage ring tunnel. On-axis swap-out injection requires special fast pulsers and state-of-the-art stripline kicker magnets (see Fig. 6).

Prototype high-voltage pulsers, based on inductive and transmission-line adder technology, have been developed and tested [7]. We have demonstrated pulses with the necessary very short rise and fall times, as well as the required flat-top length and flatness for an inductive adder (see Fig. 7).

To fully demonstrate the technology for swap out, we have finished the first stripline kicker prototype [8] and will install a second in the current ALS at the beginning of 2017.

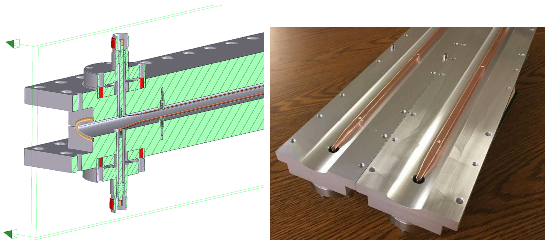

Figure 6: (Left) CAD model of stripline kicker with small gap and tapered electrodes. (Right) Prototype of stripline kicker.

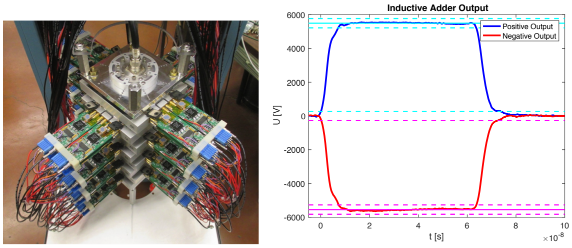

Figure 7: (Left) Full assembly (8 stages) of inductive adder. (Right) Voltage output of inductive adder at 105% of nominal setpoint.

Vacuum System - NEG Coating

The most promising technology for small apertures necessary are Non Evaporable Getter (NEG) coated vacuum chambers. Substantial progress has been made, both in industry, and within this R+D program, bringing NEG coated chambers with less than 6 mm diameter within reach [9]. One recent advance at LBNL was the use of Ti-Zr-V alloy wires to improve the chemical uniformity of coatings at small apertures. Challenges remain, including miniaturization of photon extraction chambers. For the smallest apertures qualification tests of the chambers becomes challenging because of the very small conductance. A test stand to quantitatively measure the sticking coefficient of small aperture NEG coatings was finished and is being tested (see Fig. 8). We are also testing necessary technologies to enable in-situ activation of the vacuum chambers.

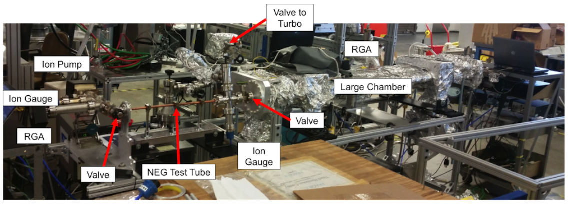

Figure 8: NEG activation test stand to quantitatively measure the stickiness coefficient, i.e. pumping speed of very small gap NEG chambers.

Harmonic Cavities

Particle-scattering effects are more important in low-emittance rings and cause growth in the equilibrium emittances (IBS) and particle loss (Touschek lifetime). The third-harmonic cavities in ALS-U are designed mitigate those effects by lengthening the bunches by roughly a factor of four. However, bunch lengthening factors at this level had not been routinely achieved in the past. The main reason are transient effects due to inhomogeneities in the fill pattern. For ALS-U, swap-out injection requires short gaps in the fill pattern presenting an inhomgeneity. The demonstrated performance of the inductive adder allows gaps as small as 10 ns, i.e. four unfilled buckets. We have replicated this fill pattern in the ALS and have demonstrated lengthening factors of about four (see Figure 9) [7].

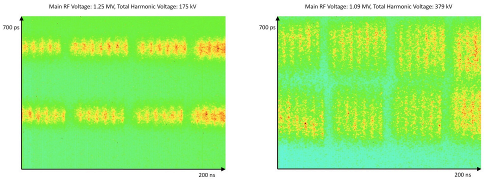

Figure 9: Streak camera images of ALS-U like bunchtrains in the ALS with harmonic cavities. (Left) main RF voltage 1.25 MV, harmonic voltage of 175 kV. (Right) main RF voltage 1.09 MV, harmonic voltage 379 kV.

With harmonic cavities and round beams, IBS becomes manageable with about 20% increase in emittance at high current. Combining the effects of radiation damping, insertion devices, coupling and IBS, we predict the emittance of the current baseline design to be about 65 pm at 500 mA.

SUMMARY

ALS-U will provide straight section rms beamsizes of around 10 microns in both planes, close to the current ALS vertical beamsize of 9 microns. The predicted soft x-ray brightness performance exceeds all ring based sources in existence or under construction and approaches the diffraction limit up to 2 keV, providing up to three orders of magnitude more coherent flux than the ALS in the few keV range. An R+D program as well as the conceptual design phase are under way. Most of the higher technical risks are in the process of being successfully retired.

REFERENCES

[1] M. Bei *et al.*, *NIM* A, `doi:10.1016/j.nima.2010.01.045`, 2010.

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

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

[4] S. Persichelli *et al.*, presented at NA-PAC'16, Chicago, IL, USA, paper THPOA33, this conference.

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

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

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

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

[9] A. Anders *et al.*, *AVS 62nd Inter. Symp.*, San Jose, CA, USA.