ISBN: 978-3-95450-247-9 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2024-TUPG38

DESIGN AND CONSTRUCTION PROGRESS OF ALS-U*

C. Steier†, J. Bohon, K. Chow, C. Espino-Devine, T. Hellert, M. Johansson, J. Joseph, J.-Y. Jung, R. Leftwich-Vann, D. Leitner, H. Lee, A. Lodge, M. Lerche, T. Luo, R. Miller, D. Nett, B. Nicquevert, O. Omolayo, A. Ratti, D. Robin, C. Sun, C. Swenson, S. Trovati, M. Venturini, W. Waldron, E. Wallen, D. Wang, LBNL, Berkeley, CA, USA
G. Ganetis, BNL, Upton, NY, USA

Abstract

The ALS-U project to upgrade the Advanced Light Source to a multi bend achromat lattice received CD-3 approval in 2022 marking the start of the construction phase for the Storage Ring. Construction of the accumulator under a prior CD-3A authorization is already well advanced. ALS-U promises to deliver diffraction limited performance in the soft x-ray range by lowering the horizontal emittance to about 70 pm rad resulting in two orders of magnitude brightness increase for soft x-rays compared to the current ALS. The design utilizes a nine bend achromat lattice, with reverse bending magnets and on-axis swap-out injection utilizing an accumulator ring. It is optimized to produce intense beams of soft x-rays, which offer spectroscopic contrast, nanometer-scale resolution, and broad temporal sensitivity. This paper presents the final design, prototype results as well as construction progress.

INTRODUCTION

To achieve diffraction-limited performance for soft x-rays, ALS-U uses a nine bend achromat lattice [1, 2] with on-axis swap out injection [3] using a full-energy accumulator. Figure 1 shows a CAD model of one of the 12 sectors with the nine bend achromat mounted on four rafts and plinths.

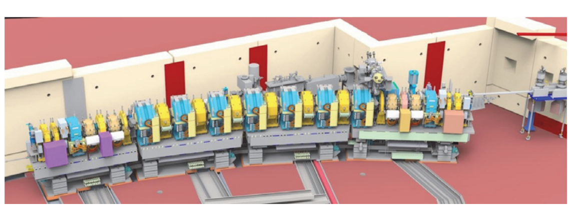

Figure 1: CAD model of one of the 12 sectors of the ALS-U Storage Ring.

The improvement in brightness and coherent flux (see Fig. 2) will be achieved by a big reduction of the emittance as well as smaller horizontal beta functions and insertion devices with smaller gaps (vertically and horizontally).The 9 bend achromat design with reverse bends produces round beams of 69 pm rad emittance, about 30 times smaller than the horizontal emittance of the existing ALS. ALS-U received approval to start construction (CD-3) from DOE/BES in November 2022 after the final design was substantially completed. Accumulator construction had started earlier based on a CD-3A approval for long lead procurements. Table 1 summarizes the main accelerator parameters compared to the current ALS.

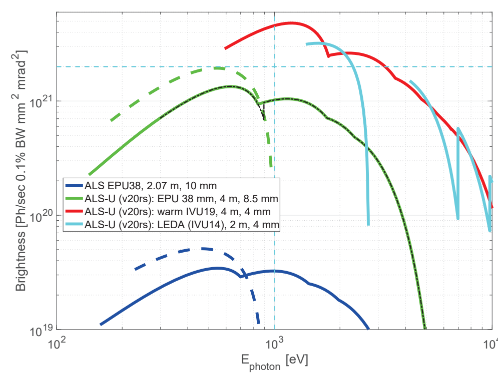

Figure 2: Brightness of existing and planned insertion devices with ALS-U beam parameters compared to the present day ALS, showing ≥2 orders of magnitude improvement at 1 keV.

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	69 pm rad
Vert. emittance	30 pm rad	69 pm rad
rms beam size (IDs)	251 / 9 µm	12 / 14 µm
rms beam size (bends)	40 / 7 µm	7 / 10 µm
Energy spread	0.97×10^{-3}	0.98×10^{-3}
Bunch length (FWHM)	60–70 ps (harm. cavity)	110 ps (harm. cavity)
Circumference	196.8 m	196.5 m
Bend magnets per arc	3	9
Total beam lifetime	6 h	≃1 h

LATTICE DESIGN

The ALS-U lattice was designed using multi objective generic algorithms and has remained stable over the preliminary and final design phases [2]. It uses 9 bending magnets, as well as 10 offset quadrupoles per arc which provide about 10% reverse bending. Six high field bending magnets with ≥3.2 T field are included in three arcs to support the twelve

* 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

ISBN: 978-3-95450-247-9 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2024-TUPG38

existing hard x-ray beamline ports. The predicted Touschek lifetime is about 1.0 h taking into account lattice errors and physical apertures. The adoption of frequent on-axis swap-out injection allowed to optimize the lattice for the small emittance and beta function.

A complete impedance budget [4–6] and numerical models for short-range wake functions were developed. Simulations show the single-bunch instability threshold with harmonic cavities and moderate chromaticity to be well above the design current. Multibunch instability growth rates are acceptable with the existing, partially damped ALS cavities. Special care was given to the effects of harmonic cavities on multi bunch instabilities [7]. Based on these results a harmonic cavity design with reduced R/Q is being constructed. Scattering effects cause emittance growth (IBS) and induce particle loss (Touschek). Mitigations include harmonic cavities, round beams, and maximizing the occupation of the RF buckets. Thanks to these provisions, scattering effects are manageable.

Commissioning Simulations

Similar to other MBA designs, advanced algorithms are needed to successfully commission ALS-U [8–10]. Simulation of beam-based commissioning shows that design lifetimes can be reached with reasonable tolerances including alignment. The newly developed algorithms have been been integrated into the ALS control system and significant parts of the software have been successfuly tested with beam on the current ALS. Figure 3 shows an example of beam-based alignment using only first turn trajectory data. Convergence was demonstrated to similar accuracy as with a more conventional stored beam beam-based alignment. This will be important for ALS-U commissioning, since an initial round of trajectory based beam-based alignment is expected to be necessary to achieve stored beam.

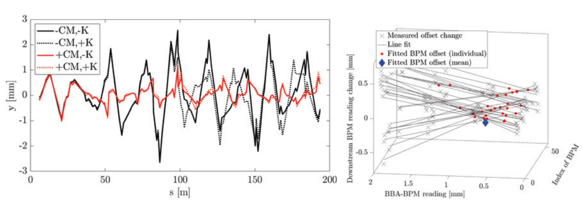

Figure 3: Demonstration of beam-based alignment using only first turn trajectory data on the current ALS.

ENGINEERING DESIGN

Key technologies for ALS-U were demonstrated early in the R&D phase [11, 12]. This included the pulsers and stripline kickers for swap-out injection, high gradient electromagnets, NEG coating of small aperture chambers, and large bunch lengthening factors with passive harmonic cavities [13–15].

One significant design challenge for ALS-U was the restricted space in the existing ALS tunnel, as well as the diversity of photon beamline designs and front ends. Together with the need for an accumulator ring and 3 new transfer lines, significant space management and engineering integration effort was needed to complete the design.

For all major subsystems, prototypes were used to verify designs and establish realistic performance estimates. A dedicated new magnetic measurement facility was built at LBNL to verify magnetic performance and NEG coating facilities were added to develop capabilities to coat smaller vacuum apertures (down to 6 mm). Magnet designs for the storage ring make extensive use of CoFe material for magnet poles and a novel asymmetric quad-bender design is used for transverse gradient dipoles. Prototype magnets achieved the required field gradients and magnetic field quality with multipoles within specifications.

In addition to individual prototypes, integrated prototype assemblies were also completed. This included vacuum strings, integration mockups, and raft assemblies for vibration and alignment tests (see Fig. 4). Vibration measurements show that the integrated raft and magnet assemblies have high first resonant mode frequencies resulting in small vibration levels of all magnets. It is expected that with crediting a modest fast orbit feedback performance, at the level that is achieved on the present day ALS, the orbit stability goals of less than 1/10 of a beamsize will be achieved with a significant safety margin on ALS-U.

Figure 4: Two examples of ALS-U integrated prototyping. (Left) Raft and plinth assembly with magnets for vibration and alignment test. (Right) Vacuum string assembly with dummy magnets for vacuum and integration tests.

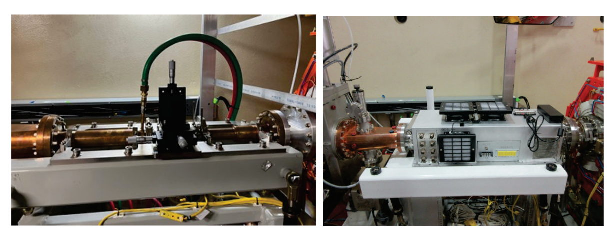

Figure 5: Two examples of ALS-U prototype hardware installed for beam tests in the current ALS ring. (Left) 13 mm inner diameter RF bellows (Right) Accumulator injection kicker and ceramic vacuum chamber.

Beam Tests of Components

To reduce risks, many hardware components for ALS-U have been tested on the current ALS and in some cases also at other rings (NSLS-II). This started early on with the swap-out kicker and pulser. More recently kickers [16] and ceramic vacuum chambers for the accumulator, RF bellows

ISBN: 978-3-95450-247-9 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2024-TUPG38

(with the internal RF finger assembly) and various prototype BPM buttons have been tested (see Fig. 5). Especially the RF bellows test retired significant risk, since the small aperture size of ALS-U (with 13 mm inner diameter RF finger assemblies) presented new design and manufacturing challenges.

MANUFACTURING

Supply chain disruption due to the COVID-19 pandemic presented many challenges, including the inability to travel for extended periods during accumulator construction and parts shortages requiring redesign in particular of electronics circuits. However, manufacturing of the accumulator is now almost complete and it is well under way for the storage ring. The magnet measurement facility at LBNL has been optimized to allow sufficient throughput of magnets and was successfully used to test, qualify and fiducialize accumulator magnets during the last year (see Fig. 6).

Figure 6: (Left and Middle) Prototype and production magnets in magnetic measurement facility. (Right) One of the three accumulator RF cavities.

Assembly

To minimize the duration of the dark period, pre-staging of complete assemblies has been adopted as an important execution strategy. This will be especially important later in for the storage ring installation during the dark period. The same strategy has also been applied for the accumulator. Complete assemblies are completed ahead of time allowing for an efficient use of regular ALS shutdowns (see Fig. 7) while allowing ALS user operations to continue until the start of the dark period. To optimize the assembly process, it has been found to be essential to develop all details of the process early with first articles of all hardware components and document it in detailed work instructions and acceptance control lists. To improve efficiency, some of the work is collaboratively carried out with SLAC.

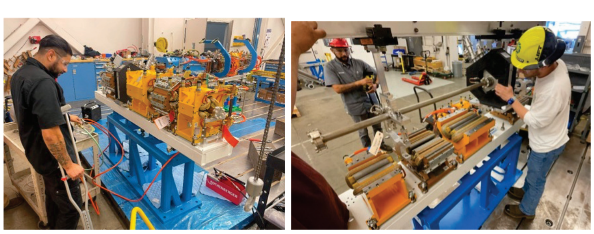

Figure 7: (Left) Hydraulic test of a raft assmebly. (Right) Installation of vacuum string after splitting of magnets.

INSTALLATION

In order to reduce the duration of the dark period and reduce the commissioning risk, the accumulator ring is being build and installed early and will be commissioned ahead of the dark period. Installation is progressing well and is closely coordinated with ALS operations. The installation happens during normal annual maintenance shutdowns of the ALS. Several complete sectors of magnet, vacuum and support hardware has been installed (see Fig. 8) and the first sector has been vacuum tested [17].

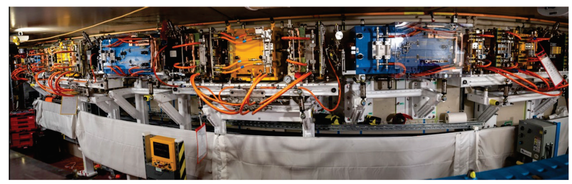

Figure 8: First completed arc of accumulator installed in the ALS tunnel.

While much of the electrical work for the accumulator will be carried within the coming year, the main dipole power supply for the booster synchrotron is already being installed now and will be commissioned this summer (see Fig. 9). It allows to increase the booster energy from 1.9 to 2.0 GeV. The commissioning of this power supply will be more complex than the beam tests of ALS-U hardware carried out so far and will be a good opportunity to refine the ALS/ALS-U coordination to carry out complex commissioning tasks.

Figure 9: Installation of new booster bend power supply to increase booster energy to 2.0 GeV.

SUMMARY

The final design of ALS-U has been completed including successful evaluation of many prototypes. Manufacturing of the accumulator hardware is almost complete and assembly and installation during normal ALS shutdowns is well underway. Manufacturing of the storage ring hardware has started. Commissioning of the accumulator ring is planned for late 2025 and the one-year dark period to install and commission the storage ring is planned to start in 2026. Once commissioned, ALS-U promises to achieve diffraction limited performance for soft x-rays.

ISBN: 978-3-95450-247-9 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2024-TUPG38

REFERENCES

[1] H. Tarawneh *et al.*, "ALS-II, a potential soft X-ray, diffraction limited upgrade of the Advanced Light Source", *J. Phys. Conf. Ser.*, vol. 493, p. 012020, 2014. doi:10.1088/1742-6596/493/1/012020

[2] C. Sun *et al.*, "Optimization of the ALS-U Storage Ring Lattice", in *Proc. IPAC'16*, Busan, Korea, May 2016, pp. 2959–2961. doi:10.18429/JACoW-IPAC2016-WEPOW050

[3] M. Borland, "Concepts and performance for a next-generation storage ring hard x-ray source", *AIP Conf. Proc.*, vol. 1234, pp. 911-914, 2010. doi:10.1063/1.3463364

[4] Z. Pan *et al.*, "Beam-Loading Transients and Bunch Shape in the Operation of Passive Harmonic Cavities in the ALS-U", in *Proc. IPAC'18*, Vancouver, Canada, Apr.-May 2018, pp. 3298–3300. doi:10.18429/JACoW-IPAC2018-THPAK037

[5] D. Wang *et al.*, "Broadband impedance modeling and single bunch instabilities estimations of the advanced light source upgrade project", *Nucl. Instrum. Methods Phys. Res., Sect. A*, vol. 1031, p. 166524, May 2022. doi:10.1016/j.nima.2022.166524

[6] D. Wang *et al.*, "Impedance evaluation, mitigation, and measurement of ALS-U vacuum components.", presented at the IPAC'24, Nashville, TN, USA, May 2024, paper TUPC13, this conference.

[7] M. Venturini, "Passive higher-harmonic rf cavities with general settings and multibunch instabilities in electron storage rings", *Phys. Rev. Accel. Beams*, vol. 21, p. 114404, Nov. 2018. doi:10.1103/PhysRevAccelBeams.21.114404

[8] T. Hellert, Ph. Amstutz, C. Steier, and M. Venturini, "An Accelerator Toolbox (AT) Utility for Simulating the Commissioning of Storage-Rings", in *Proc. IPAC'19*, Melbourne, Australia, May 2019, pp. 1441–1444. doi:10.18429/JACoW-IPAC2019-TUPGW021

[9] Ph. Amstutz and T. Hellert, "Iterative Trajectory-Correction Scheme for the Early Commissioning of Diffraction-Limited Light Sources", in *Proc. IPAC'19*, Melbourne, Australia, May 2019, pp. 353–356. doi:10.18429/JACoW-IPAC2019-MOPGW098

[10] T. Hellert, C. Steier, M. Venturini, "Lattice correction and commissioning simulation of the Advanced Light Source upgrade storage ring", *Phys. Rev. Accel. Beams*, Vol. 25, p. 110701, Nov. 2022. doi:10.1103/PhysRevAccelBeams.25.110701

[11] C. Steier, "Possibilities for a Diffraction-Limited Upgrade of a Soft X-ray Light Source", *Synchrotron Radiat. News*, vol. 27, no. 6, pp. 18-22, Nov. 2014. doi:10.1080/08940886.2014.970934

[12] C. Steier *et al.*, "Progress of the R&D towards a diffraction limited upgrade of the Advanced Light Source", in *Proc. IPAC'15*, Richmond, VA, USA, May 2015, pp. 1840–1842. doi:10.18429/JACoW-IPAC2015-TUPMA001

[13] S. De Santis *et al.*, "Injection/Extraction Kicker for the ALS-U Project", in *Proc. IPAC'14*, Dresden, Germany, Jun. 2014, pp. 1977–1979. doi:10.18429/JACoW-IPAC2014-WEPRO016

[14] C. Steier *et al.*, "Design Progress of ALS-U, the Soft X-ray Diffraction Limited Upgrade of the Advanced Light Source", in *Proc. IPAC'19*, Melbourne, Australia, May 2019, pp. 1639–1642. doi:10.18429/JACoW-IPAC2019-TUPGW097

[15] W. L. Waldron, D. A. Dawson, S. De Santis, T. Oliver, and C. Steier, "Injection and Extraction Kickers for the Advanced Light Source Upgrade Project (ALS-U)", in *Proc. IPAC'21*, Campinas, Brazil, May 2021, pp. 3487–3489. doi:10.18429/JACoW-IPAC2021-WEPAB341

[16] M. Ehrlichman *et al.*, "Three-dipole kicker injection scheme for the Advanced Light Source upgrade accumulator ring", *Phys. Rev. Accel. Beams*, vol. 24, p. 120702, Dec. 2021. doi:10.1103/PhysRevAccelBeams.24.120702

[17] T. Griesemer *et al.*, "ALS-U accumulator ring raft and dipole installation", presented at the IPAC'24, Nashville, TN, USA, May 2024, paper TUPG35, this conference.