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DESIGN PROGRESS OF ALS-U, THE SOFT X-RAY DIFFRACTION LIMITED UPGRADE OF THE ADVANCED LIGHT SOURCE*

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Abstract

The ALS-U project to upgrade the Advanced Light Source to a multi bend achromat lattice received CD-1 approval in 2018 marking the end of its conceptual design phase. The ALS-U design 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. This paper presents recent design progress of the accelerator, as well as new results of the R&D program.

INTRODUCTION

To achieve diffraction-limited performance for soft x-rays, ALS-U uses a nine bend achromat lattice (see Fig. 1) with on-axis swap out injection and a full energy accumulator.

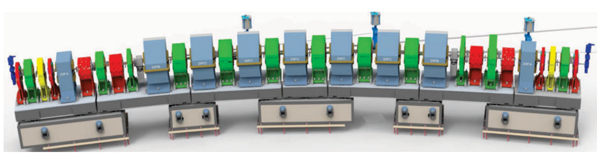

Figure 1: CAD model of ALS-U showing one of the twelve sectors of the nine bend achromat lattice as well as the support system based on plinths and rafts.

The improvement in coherent flux at 1 keV of at least two orders of magnitude compared to ALS (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 [1, 2].

The design produces round beams of 70 pm rad emittance, about 30 times smaller than the horizontal emittance of the existing ALS. ALS-U received CD-1 approval from DOE/BES in September 2018 marking the end of the conceptual design and start of the preliminary design phase. Table 1 summarizes the main accelerator parameters.

During the ALS-U R&D program, which is now coming to a successful end, many improvements were demonstrated relating to swap-out injection, harmonic cavities with large lengthening factors [3, 4], vacuum design/NEG coating, high gradient magnets, and beam diagnostics [5].

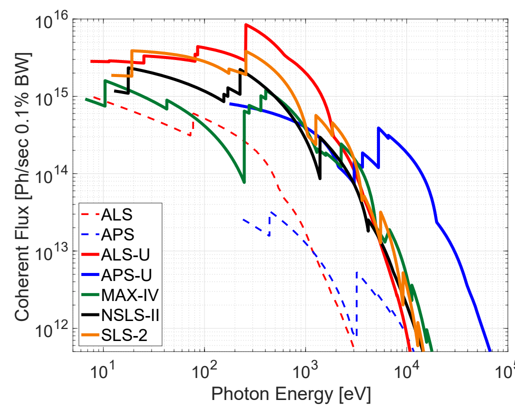

Figure 2: Coherent flux of planned new insertion devices on ALS-U compared to existing and planned rings, showing ≥2 orders of magnitude improvement at 1 keV compared to the ALS.

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	70 pm rad
Vert. emittance	30 pm rad	70 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}	1.04×10^{-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

The ALS-U lattice has been stable over the last year. 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 existing hard x-ray beamline ports. The predicted Touschek lifetime is about 1.5 h taking into

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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.

Commissioning Simulations

Work has concentrated on studying and improving the lattice robustness, correction of insertion device effects [6], as well as time dependent errors. Especial emphasis was put on developing a complete set of commissioning algorithms [7, 8]. Similar to other MBA designs, these advanced algorithms will be needed to successfully commission ALS-U. Fully developing and testing these algorithms already during the design phase allows to define reasonable alignment and error tolerances for magnets, power supplies and diagnostics. Lattice correction using LOCO while considering diagnostics errors was simulated (see Fig. 3) and shows successful restoration of the lattice symmetry resulting in acceptable lifetimes, slightly exceeding the 1.5 h predicted with simplified error sets.

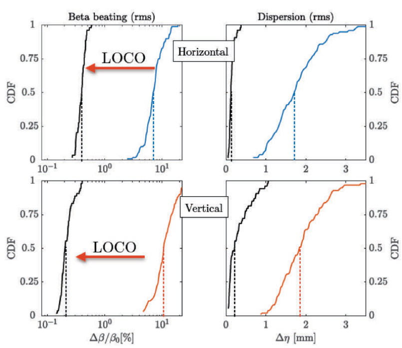

Figure 3: Predicted improvement in beta beating and dispersion error with LOCO correction.

COLLECTIVE EFFECTS AND IBS

A conceptual impedance budget 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 above the design current. Multibunch instability growth rates are acceptable with the existing, partially damped ALS cavities (see Fig. 4).

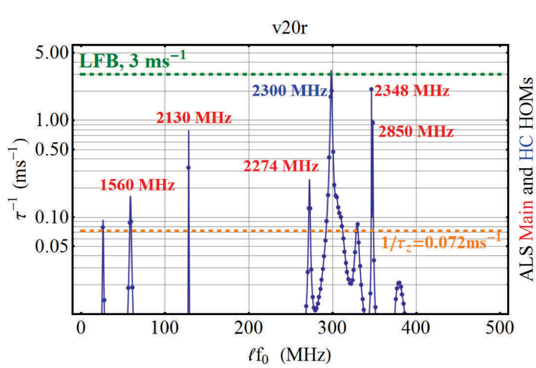

Figure 4: ALS-U longitudinal multibunch instability growth rates with the existing, partially damped RF cavities.

A lot of recent work has focused on the effects of harmonic cavities on multi bunch instabilities. The picture here is complex depending on the parameter regime they might decrease or increase growth rates [9]. Based on these results a new harmonic cavity design with optimized shunt impedance is being pursued. 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.

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 are required to achieve the target emittance. The latter will be realized with radially off-set geometric quadrupoles; we have selected an innovative C-shaped design with asymmetric pole-design (C) that promises good field quality but reduced mass and power consumption (see Fig. 5). A prototype of a magnet with this design, which incorporates most of the novel features of the ALS-U magnets, including swept CoFe poles, was completed.

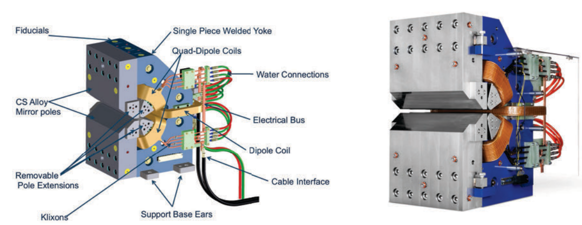

Figure 5: (Left) Design of the transverse gradient dipole which is being built as the first R&D magnet to demonstrate the critical technical features of ALS-U magnets. (Right) Completed magnet prototype.

Magnetic measurements with 3d Hall probe mapping show that the prototype meets the magnetic design goals, including dipole field, quadrupole field, and systematic as well as random magnet errors. Fig. 6 shows the measured dipole field component along the beam trajectory.

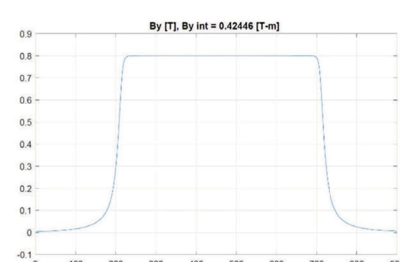

Figure 6: Measured dipole field along the beam trajectory for the prototype transverse gradient bend magnet.

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VACUUM AND SUPPORTS

The most promising technology to achieve good vacuum pressures with the necessary small apertures are Non Evaporable Getter (NEG) coated vacuum chambers. Substantial progress has been made at LBNL and NEG chambers with 6 mm inner diameter have been coated. Similar H_2 and CO pumping performance as the best values reported for larger chambers has been achieved. A larger test chamber coated at LBNL was installed in the ALS (see Fig. 7). The ALS-U vacuum design uses a hybrid vacuum system design, that deploys NEG coating where needed (≈50% of chambers). Predicted vacuum lifetimes fulfill the requirements. A number of small scale prototype chambers have been completed, including a photon beam egress chamber (see Fig. 7).

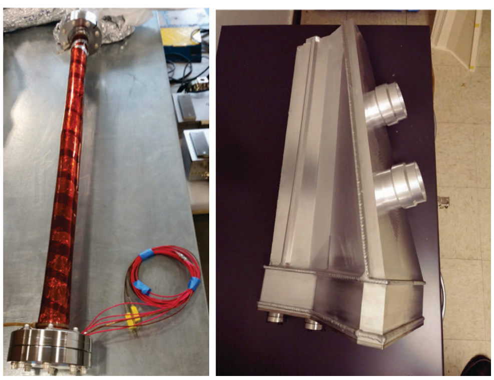

Figure 7: (Left) LBNL NEG coated vacuum chamber installed for testing at ALS. (Right) Prototype of photon beam egress chamber.

ALS-U plans to use plinths and rafts. There are 5 concrete plinths per sector and 7 rafts. Prototypes of the rafts and of the positioning and clamping system are almost complete and will be tested for alignment accuracy and vibration performance in the next months (see Fig. 8). Prototype supports were also completed for the accumulator ring, including simulated magnet loads and will be mounted in the ALS tunnel to evaluate their vibration performance and the accuracy of the FEA modeling.

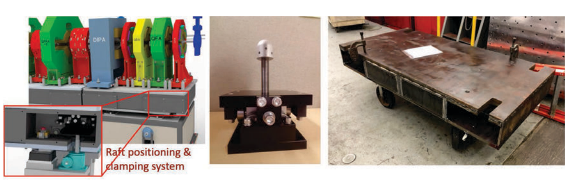

Figure 8: (Left) CAD model of interface between plinths and rafts. (Middle and Right) Examples of support prototypes.

ACCUMULATOR AND SWAP-OUT

On axis-injection [10,11] with bunch train swap-out and a full energy accumulator ring will be used. The accumulator will be housed in the storage ring tunnel [12] and will act as a damping ring (see Fig. 9). It will be installed over several years during regular ALS shutdowns and commissioned before the final one year dark period when the storage ring will be installed [13] and commissioned.

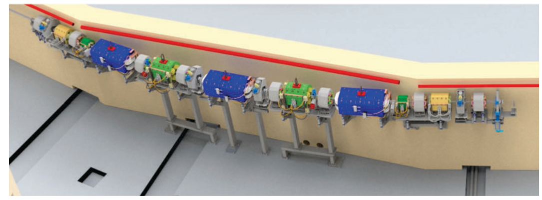

Figure 9: Mounting scheme for the accumulator on the inner shielding wall of the storage ring.

Its lattice will allow for off-axis injection from the booster and the extracted low emittance beam is injected on-axis into ALS-U. This allows ALS-U to be fully optimized for brightness. The main technical challenge were the fast magnets and pulsers needed for swap-out. We developed, installed and tested a full prototype system of a small (6 mm) gap stripline kicker and an inductive adder (5.5 kV) on the ALS [14]. The stripline kicker has been installed for 1.5 years of user beam operations. It is fully integrated in the ALS control and timing system. It uses the same very small aperture as the ALS-U system and has been tested, including the loads and termination at the pulser in all ALS fill patterns. ALS-U due to the longer bunch length has lower beam induced voltage and power than in the ALS test.

Recently, a second iteration of the pulser demonstrated improved fall-times (see Fig. 10). The measurements used a single bunch in the ALS together with the turn-by-turn BPM system to map the effective kick a bunch sees depending on the delay relative to the kick with very high accuracy. This test verified the rise and fall-time performance needed for ALS-U.

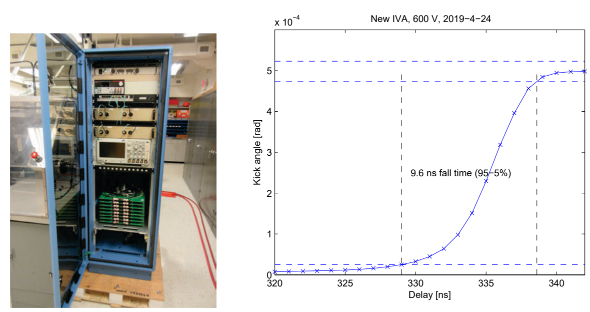

Figure 10: (Left) Second iteration of inductive voltage adder. (Right) Beam based measurement of the kick angle versus delay of the kicker pulse versus a single bunch. The falling flank of the pulse is shown.

SUMMARY

The storage ring and accumulator ring for ALS-U are currently in the preliminary design phase. Most of the accelerator R&D activities have been completed. It is planned to start long lead procurements later this year. ALS-U promises to achieve diffraction limited performance for soft x-rays up to 2 keV.

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