ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-THPMF036

STATUS OF THE CONCEPTUAL DESIGN OF ALS-U*

C. Steier†, A. Allézy, A. Anders, K. Baptiste, E. Buice, K. Chow, G. Cutler, R. Donahue, D. Filippetto, J. Harkins, T. Hellert, M. Johnson, J.-Y. Jung, S. Leemann, D. Leitner, 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, S. Virostek, W. Waldron, E. Wallén, LBNL, Berkeley, CA 94720, USA

Abstract

The ALS-U conceptual 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 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 shows some aspects of the completed conceptual design of the accelerator, as well as some results of the R&D program that has been ongoing for the last years.

INTRODUCTION

To achieve diffraction-limited performance for soft x-rays, ALS-U uses a nine bend achromat lattice with on-axis swap out injection. The improvement in coherent flux 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). This requires to replace the existing triple bend achromat lattice with a multi bend Achromat (MBA) lattice [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 approval of Mission Need (CD-0) from DOE/BES in September 2016 and the conceptual design was finished in spring 2018 and has been reviewed by a series of nine external technical reviews. Table 1 summarizes the main accelerator parameters and Figure 1 shows the nine bend achromat including the magnet supports based on plinths and rafts.

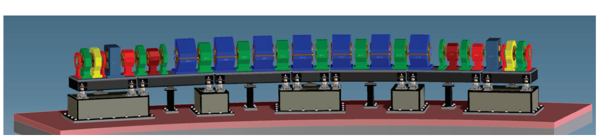

Figure 1: CAD model of ALS-U showing one of the twelve sectors of the nine bend achromat lattice as well as the support system based on plinths and rafts.

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 with the goal of reducing the technical risks. The main areas studied were swap-out injection, harmonic cavities with large lengthening factors [3,4], vacuum design/NEG coating, and high gradient magnets. Substantial progress has been made in all areas and an improvement in brightness by two orders of magnitude at 1 keV is achievable (see Figure 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	70 pm rad
Vert. emittance	30 pm rad	70 pm rad
rms beam size (IDs)	251 / 9 µm	≤14 / ≤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)	120–140 ps (harm. cavity)
Circumference	196.8 m	~196.5 m
Bend magnets per arc	3	9

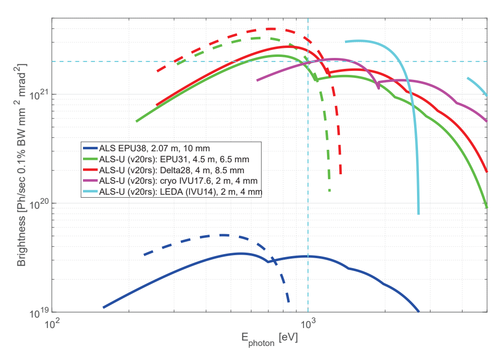

Figure 2: Soft x-ray brightness of planned new insertion devices on ALS-U compared to th existing ALS showing 2 orders of magnitude improvement at 1 keV.

LATTICE

During the conceptual design phase, a defined process was used to improve the lattice and, once a significant improvement was achieved, to update the baseline lattice, after evaluating the impact on the design of the individual technical systems. The work first focused on making the lattice more robust to errors, and to improve the lifetime. Later on, 5 T Superbends were included to maintain the ALS hard

* 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

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x-ray capabilities. Finally, reverse bending magnets were included to lower the natural emittance. The resulting lattice uses 9 bending magnets, as well as 10 offset quadrupoles per arc which provide about 10% reverse bending. Six Superbend magnets with 5 T field [5] are included in three arcs to support the twelve existing hard x-ray beamline ports. Figure 3 shows the dynamic and momentum aperture as well as Touschek lifetime of about 1.5 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 and allows to successfully handle the short lifetime. Beam based lattice correction is essential during the commissioning period [6].

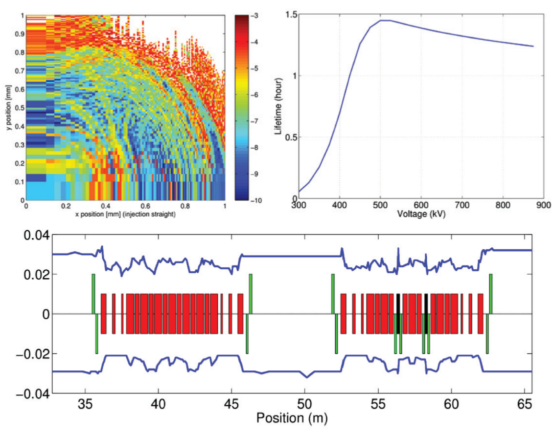

Figure 3: (Top Left) Frequency map for the 9BA lattice. (Bottom) Local momentum aperture for two periods including Superbends. (Top Right) Touschek lifetime as a function of RF voltage. All calculations include lattice errors and physical apertures.

The baseline lattice fulfills all high level project goals, including emittance, brightness, lifetime, as well as the ability to maintain the ALS hard x-ray capability. Other lattice options were studied as well, including hybrid MBAs with longitudinal gradients, different numbers of bending magnets, and an MBA design with combined longitudinal/transverse gradient magnets [7]. However, overall it was deemed that the 9BA with reverse bends and Superbends was the preferred choice.

COLLECTIVE EFFECTS

Because of the narrow vacuum chamber aperture (13 to 20 mm in the arcs; as small as 6 mm in the straights) the resistive wall impedance is a large contributor to the overall impedance. We have developed a conceptual impedance budget using numerical models for the short-range wake functions and their effects on the beam. Preliminary results show the single-bunch instability threshold with moderate chromaticity and harmonic cavities to be comfortably above the design current (see Fig. 4).

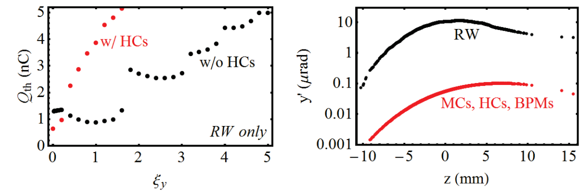

Figure 4: (Left) TMCI threshold as a function of chromaticity. (Right) Transverse wakefield kick due to resistive wall effect in small gap undulator chambers as well as selected other impedance sources.

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). The planned operating energy of ALS-U at 2.0 GeV is just above the beam energy at which the minimum emittance (including IBS) is achieved. The Touschek lifetime of the current baseline is about 1.5 h at 500 mA. The radiation damping of undulators helps to counteract some the emittance increase due to IBS. This effect of course depends on photon energy settings of each undulators [8]. A model has been developed based on historical data on the ALS and the prediction is that the emittance for ALS-U will be constant to a few percent for typical undulator operation. The average emittance with all effects included for the baseline lattice is 70 pm rad.

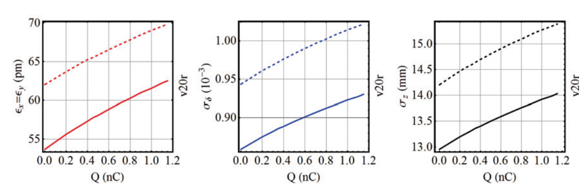

Figure 5: Emittance, energy spread and bunchlength increase due to IBS as a function of current for nominal fill pattern, round beams, harmonic cavities, both with and without the damping effect of a typical set of undulators.

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 are required to achieve the target emittance. The latter will be realized with radially off-set geometric quadrupoles. To minimize power consumption and magnet size, we use a C-shaped design with asymmetric poles (see Fig. 6). The production of an R&D demonstration magnet with this design has

9th International Particle Accelerator Conference IPAC2018, Vancouver, BC, Canada JACoW Publishing
ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-THPMF036

started. Further prototype magnets have been designed and production of those will start soon [9, 10].

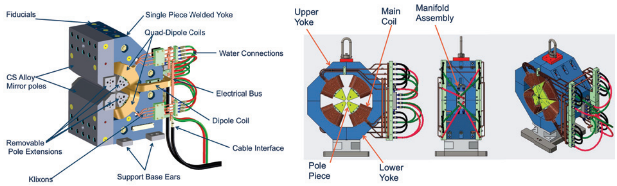

Figure 6: (Left) Design of the transverse gradient dipole which is being built as the first R&D magnet to demonstrate the critical technical features of ALS-U magnets. (Right) Design of the reverse bend quadrupole starting construction.

ACCUMULATOR AND SWAP-OUT

On axis-injection [11, 12] with bunch train swap-out and a full energy accumulator ring will be used. The accumulator will be housed in the storage ring tunnel and will act as a damping ring (see Figure 7).

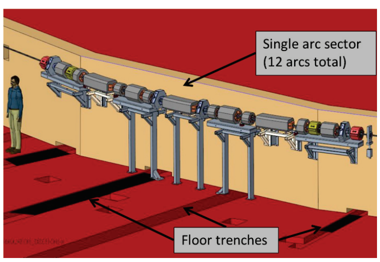

Figure 7: Mounting scheme for the accumulator on the inner shielding wall of the storage ring.

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 of swap-out before the start of our R&D program was the fast magnets and pulsers needed for swap-out. To retire this risk, we designed, built, 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 (see Figure 8). The in-house designed inductive voltage adder has demonstrated pulses with the necessary very short rise times [13].

The stripline kicker has been installed for about one year in the ALS and has been tested in all fill patterns and operations modes. The TMCI threshold is the same as without the kicker and the heating of the kicker is manageable. Kicking the ALS beam with the stripline kicker and using turn-by-turn BPMs measurements of the pulse amplitude, duration, and shape, as well as reproducibility were carried out. The results confirm that the system fulfills the requirements.

VACUUM

The most promising technology to achieve good vacuum pressures with the small apertures necessary are Non Evaporable Getter (NEG) coated vacuum chambers. Substantial

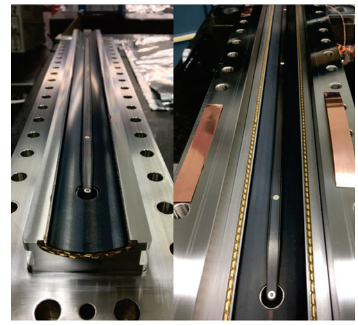

Figure 8: Top and bottom section of the stripline kicker with 6 mm full aperture, which is installed in the ALS.

progress has been made, bringing NEG coated chambers with less than 6 mm diameter within reach. The conceptual design of the ALS-U vacuum system has been completed (see Fig. 9) and pumping tests with 6 mm inner diameter copper vacuum chambers that have been NEG coated at LBNL have shown H_2 stickiness coefficients close to the best values reported for larger chambers.

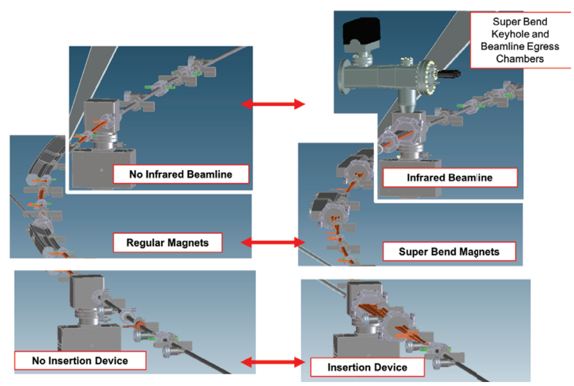

Figure 9: Conceptual layout of the arc sector vacuum chamber, photon extraction ports and absorbers.

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) there are path length contraints for two of the transfer lines. A feasible conceptual design for the three transfer lines connecting booster, accumulator and storage ring has been finished, that fulfills all physics requirements.

SUMMARY

A conceptual design of ALS-U has been completed. It uses a nine bend achromat lattice with reverse bending magnets and promises to achieve diffraction limited performance for soft x-rays up to 2 keV. In parallel, an R&D program has been successful in reducing major technical risks.

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