R+D PROGRESS TOWARDS A DIFFRACTION LIMITED UPGRADE OF THE ALS*

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Abstract

Improvements in brightness and coherent flux of about two orders of magnitude over operational storage ring based light sources are possible using multi bend achromat lattice designs [1]. These improvements can be implemented as upgrades of existing facilities, like the proposed upgrade of the Advanced Light Source, making use of the existing infrastructure, thereby reducing cost and time needed to reach full scientific productivity on a large number of beamlines. An R&D program was started at LBNL to further develop the technologies necessary for diffraction-limited storage rings. It involves many areas, and focuses on the specific needs of soft x-ray facilities [2]: NEG coating of small chambers, swap-out injection, bunch lengthening, magnets/radiation production, x-ray optics, and beam physics design optimization. Hardware prototypes have been built and concepts and equipment was tested in beam tests on the existing ALS.

INTRODUCTION

The ALS-U design replaces the ALS storage ring's triple-bend achromat magnetic lattice with a stronger-focusing nine-bend achromat (see Fig. 1) [3,4]. Such an achromat is enabled by advances in non-evaporable getter (NEG)–coated vacuum chambers that allow vacuum apertures ≤ 20 mm in diameter. ALS-U will produce round beams of approximately 50 pm-rad emittance. This horizontal emittance is 40 times smaller than that of the existing ALS and is the biggest contributor to the increase in coherent flux.

One of the consequences of producing such a small emittance is that there is a reduction in the dynamic aperture, which makes traditional off-axis injection difficult, although the momentum acceptance will remain large enough to support good beam lifetime. To overcome this challenge, ALS-U will use on-axis swap-out injection to exchange beam bunch trains between the storage ring and a low-emittance, full-energy accumulator ring. The swap-out mechanism will enable a generational leap in performance. Not only does it allow operating with ultralow emittance, it also makes it possible to employ very small, round chambers in the insertion-device straight sections. These small chambers, in turn, enable higher-performance undulators. ALS-U will provide the highest coherent flux of any existing or planned

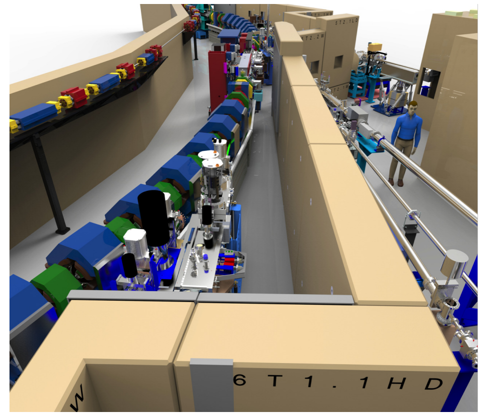

Figure 1: CAD model of ALS-U showing the existing accelerator tunnel with the new storage and accumulator rings.

storage ring up to a photon energy of 3.5 keV, which covers the entire soft x-ray regime (see Fig. 2).

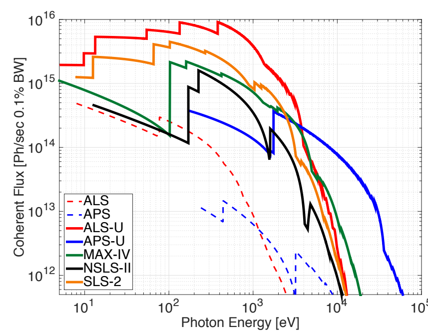

Figure 2: Coherent flux produced by selected storage-ring-based x-ray facilities.

ALS-U R+D PROGRAM

To reduce technical risks and explore new technologies that could provide a large performance advantage, 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 and is well aligned with the community consensus of remaining challenges of MBA lattices, as well as the special needs of a soft x-ray DLSR [2].

In the accelerator area, the R&D includes development programs to demonstrate pulser and kicker technology for swap-out injection, vacuum technology to enable ultimate performance of polarized undulators, hamronic rf

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systems for bunch lengthening, highly integrated and high-stability magnet and vacuum assemblies, advanced radiation-production sources, and optimization of algorithms and tools for fast commissioning.

In the area of beamlines, optical fabrication technology has advanced in the last few years to the point that surfaces can be made with sufficient accuracy to transport coherent soft x-rays. However, R&D is needed in high-power mirror technology. The current cooling schemes employed are inadequate for wavefront preservation, and a new generation of cooled optics is required.

MAGNETS AND RADIATION PRODUCTION

To achieve diffraction-limited emittances, quadrupole gradients on the order of 100 T/m are necessary, which is feasible but challenging for high-precision iron-dominated magnets. Other design goals are to provide sufficient space for the vaccuum system, low power consumption, reliability, field quality, and ability to align accurately and efficiently, to name a few. Another challenge is the very high packing density, which brings magnets into close proximity. In the case of ALS-U, the typical pole-to-pole distance between adjacent magnets is 75 mm, three times the typical pole gap of 24 mm.

Pre-conceptual designs have been finished for all magnets that are used in the baseline lattice. The magnets are all feasible; however, some of them require special materials or other design features to fit with the vacuum system and achieve sufficient field quality. Figure 3 shows the CAD drawing of the transverse-gradient dipole, a radially offset, C-shaped quadrupole magnet used for the inner seven dipoles of the nine-bend achromat and one option for superbend magnets.

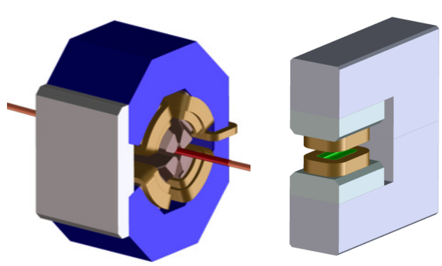

Figure 3: (Left) Conceptual design of an ALS-U transverse-gradient dipole. (Right) Compact s/c magnet with longitudinally shaped field profile to provide hard x-ray radiation.

Currently, multiple design options are being pursued for radiation-producing devices, with the possible options under investigation as part of the ongoing R&D program. The smaller vertical apertures in the ALS-U design present a new opportunity, and even more importantly, equally small horizontal apertures in some straights will enable new undulator technologies with superior performance, especially for experiments requiring polarization control. The current plan for the four new undulators includes the use of devices with polarization control, with two of them being small-gap elliptically polarizing undulators (EPUs) and two of them using more advanced technologies, such as Delta undulators or bifilar helical superconducting undulators.

The ALS experimental program makes extensive use of bending-magnet and superbend source points in addition to undulator sources. Therefore, ALS-U will have to maintain a large number of (super)bend beamlines, in addition to the insertion-device straights. Engineering studies have shown that superconducting magnets could be built small enough to fit together with two additional quadrupoles into the slot of one transverse-gradient dipole (see Fig. 3). The field at the source points would be similar to the current ALS.

COHERENCE PRESERVING X-RAY OPTICS

At ALS-U, the source size will be around 25 times smaller in the horizontal direction and will demand surface slope errors of x-ray optics approximately 25 times smaller than today's values. The present internally cooled copper solution reaches the required tolerances for ALS with the present beam size but is far short of the performance needed for ALS-U. To address this problem, we have studied internally water-cooled silicon, side-water-cooled silicon, internally liquid nitrogen (LN2)–cooled silicon, and side LN2-cooled silicon. Figure 4 illustrates one case, that of side-water-cooled silicon. The simulation prediction for optimally side-cooled silicon is 0.1 μrads RMS, which is well inside the tolerance required. Several avenues are being pursued to validate these simulation results and study practical implementation challenges, especially for the LN2 cooled solutions.

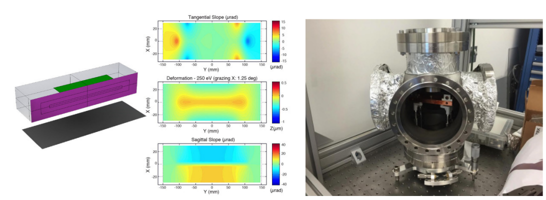

Figure 4: (Left) CAD model of a side-cooled silicon block and resulting deformation for the maximum power load. (Right) interferometric test setup for LN2 cooled Si optics.

ON-AXIS SWAP-OUT INJECTION

It is planned to use on-axis injection [2, 5] with bunch train swap-out and an accumulator ring. The new accumulator will be housed in the storage ring tunnel. It will act as a damping ring where its lattice will allow for off-axis injection from the current ALS booster and the extracted low emittance beam is injected on-axis into the small dynamic aperture of ALS-U. On-axis swap-out injection requires special fast pulsers and state-of-the-art stripline kicker magnets (see Fig. 5). Prototype high-voltage pulsers, based on inductive and transmission-line adder technology, are being developed and tested [6] to meet the requirements of ALS-U. Excellent progress has been made and we have demonstrated

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pulses with the necessary very short rise and fall times, as well as the required flat-top length and flatness for an inductive adder. We are also pursuing industrial partnerships as well as a collaboration with APS-U.

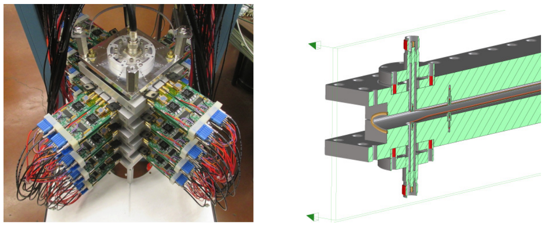

Figure 5: (Left) Full assembly (8 stages) of inductive adder. (Right) CAD model of stripline kicker with small gap and tapered electrodes.

The most effective and direct way to minimize the risks of the interaction of the storage ring beam with the small gap stripline kicker structures [7] is to build, install, and test fully functional kicker/pulser systems at facilities such as the ALS that have the necessary beam diagnostics and space and that can closely approximate the relevant beam parameters. We have finished the design of such a kicker and are currently manufacturing it. It will be installed later in 2016 for beam tests.

VACUUM SYSTEM - NEG COATING

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 within this R+D program, bringing NEG coated chambers with less than 6 mm diameter within reach [8]. 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.

We have performed detailed simulations of the performance of vacuum-chamber layouts with synchrotron radiation (see Fig. 6). Power densities and the resulting mechanical stresses on the chambers are acceptable. The simulations predict that the average pressure, despite the small vacuum apertures and correspondingly poor conductance, will be similar or better than for the current ALS (i.e. $\leq$ 0.5 nTorr).

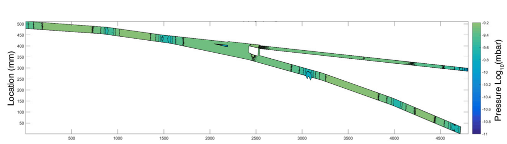

Figure 6: Synrad and Molflow simulation of an undulator photon-extraction chamber geometry with a round Cu chamber. The example chamber shown here spans about the first quarter of one ALS-U arc.

INTRABEAM SCATTERING AND HARMONIC CAVITIES

Intra Beam Scattering leads to emittance increase at larger bunch charge and is a very rapid function of the beam energy. It is more severe at 2 GeV compared to higher energy rings. Therefore, it is necessary to fill as many buckets as possible, operate with the largest vertical emittance possible, and stretch the bunch length by factors of 3-4 with harmonic RF systems. However, bunch lengthening factors at this level have not been routinely achieved so far. The main reason are transient effects due to inhomogenities in the fill pattern. Those inhomogenities can have different reasons. For ALS-U, swap-out injection requires short gaps in the fill pattern. 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, using three normal conducting, passive 3rd harmonic cavities (see Figure 7).

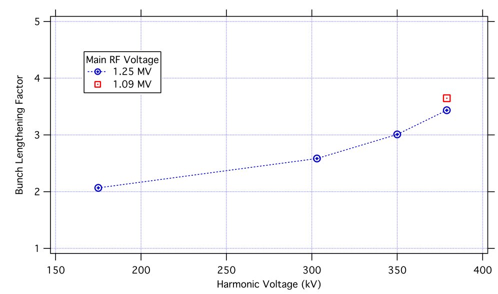

Figure 7: Measured bunch lengths with ALS-U fill pattern in the ALS for various harmonic and main RF voltages.

SUMMARY

ALS-U will provide straight section 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 is under way to refine the proposal, improve the performance and retire technical risks. many technical risks have been successfully retired.

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