INITIAL LATTICE DESIGN STUDIES FOR A DIFFRACTION LIMITED UPGRADE OF THE ADVANCED LIGHT SOURCE

H. Tarawneh#, C. Steier, D. Robin, H. Nishimura, C. Sun, W. Wan
Lawrence Berkeley National Laboratory, 1 Cyclotron Rd., Berkeley, CA 94720 USA

Abstract

The Advanced Light Source (ALS) at Berkeley Lab has seen many upgrades over the years, keeping it one of the brightest sources for soft x-rays worldwide. Recent developments in magnet technology and lattice design appear to open the door for very large further increases in brightness [1], particularly by reducing the horizontal emittance, even within the space constraints of the existing tunnel. We are investigating the possibility of a new storage ring lattice that could approach the soft x-ray diffraction limit around 2 keV in both planes within the ALS footprint.

This note presents an overview of a candidate lattice for diffraction limited ALS and describes the optimization of the dynamical performance of the lattice. In addition on-axis injection scheme is foreseen for this ring and a candidate lattice for an accumulator ring, which will be built and housed either in the ALS storage ring tunnel or the booster tunnel, is also presented.

INTRODUCTION

A new compact lattice based on Multiple Bend Achromat [2] that is going to replace the existing ALS Triple Bend Achromat is being investigated. This design study of diffraction limited ALS (ALS-II) lattice has a goal of achieving a natural emittance of about 100 pm.rad and beam energy around 2 GeV.

This candidate lattice takes advantage of the fact that the ring admittance is defined by the small gap insertion devices and hence the use of small aperture magnets. This leads to the introduction of high magnetic strength where very low emittance with short circumference can be achieved.

The small emittance achieved by the candidate ALS-II lattice requires the usage of double RF system to lengthen the bunch and to operate with round beam to mitigate the effect of Intra Beam Scattering (IBS) and for lifetime considerations [3]. Bunch lengthening will also have large impact on mitigating the effect of beam interaction with the resistive metallic chamber and the chamber geometric discontinuities due small momentum compaction factor.

The ALS-II lattice strong focusing limits the dynamic aperture to few millimetres which requires an on-axis injection scheme based on swap-out [4]. A relatively small emittance ring, Accumulator ring, is proposed to inject into the ALS-II ring as the current ALS booster has a large emittance and will not deliver full charge in a single bunch needed by the swap-out injection scheme.

In the following sections, the choice of the ALS-II lattice and characterization of its dynamical properties and performance are discussed. The bunch lengthening with double RF system and the implications on emittance, lifetime will be discussed.

Also a candidate lattice for the accumulator ring and achieved dynamic performance will be presented.

CANDIDATE ALS-II LATTICE

A study has been performed for a lattice that could approach the soft x-ray diffraction limit around 2 keV in both planes within the ALS footprint. This lattice, while not fully optimized, demonstrates the feasibility of the ALS-II concept. The new lattice is based on a Nine Bend Achromat replacing the existing ALS Triple Bend Achromat, see Figure 1. The lattice preserves the 12-fold symmetry and the circumference of the present ALS while ultimately achieving a natural emittance of about 100 pm.rad at 2 GeV beam energy. The proposed lattice follows the hybrid configuration of the ESRF upgrade design that takes advantage of a large number of combined function bending magnets to reduce the horizontal emittance [5]. The matched cell structure serves two goals, matching the dispersion to zero in the straight section since the lattice is optimized for high brightness production and to create a large horizontal dispersion bump and large beta function for efficient natural chromaticity correction. Figure 2 shows the layout of one arc of the candidate lattice.

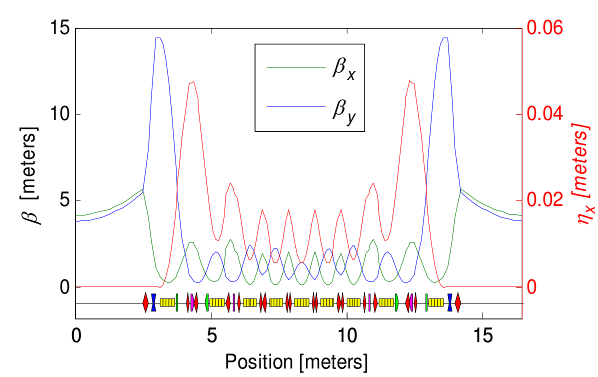

Figure 1: ALS-II candidate lattice Twiss functions.

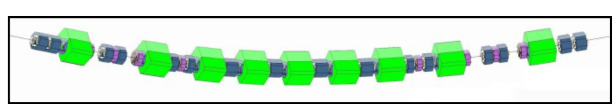

Figure 2: Layout of one arc of ALS-II lattice.

Multi-Objective Genetic Algorithm (MOGA) has been used to give an optimal solution based on the lattice elements [6]. The selected lattice provide identical optical functions in all straight sections with natural emittance of 100 pm.rad and horizontal and vertical beta functions of

(#) HITarawneh@lbl.gov

about 4 meters and zero dispersion. The choice is a compromise between matching the electron-photon phase spaces to maximize brightness at high photon energies and low natural chromaticities and hence adequate dynamic aperture needed for injection process. Table 1 summarizes the main parameters of the ALS-II lattice.

Table 1: Parameters of Candidate ALS-II Lattice

Parameter	Value
Beam energy [GeV]	2
Natural emittance [pm.rad]	100
Tune ν_x/ν_y	41.13/26.21
Natural $\xi_{x,\,y}$	-68/-64
Energy spread	8.13×10^{-4}
α_c	2.54×10^{-4}

NONLINEAR DYNAMICS

The proposed scheme for the chromaticity correction in the ALS-II lattice is based on compactness and flexibility. The small apertures in the sextupole magnets are used to introduce very strong sextupole fields. We avoided the introduction of these fields in the pole shape of the bending and quadrupole magnets where the flexibility of the lattice would have been compromised. The configuration of the matching cell which has relatively higher values of β_x, β_y and η_x functions is used to house four sextupole magnets families, two focusing and two defocusing ones, to correct the chromaticity.

The nonlinear effects driven by the strong sextupoles result in reduced dynamic aperture which hampers injection and reduces the Touschek lifetime. To overcome this, the ALS-II lattice will be operated at full coupling, i.e. with a round beam and an on-axis injection scheme. The dynamic aperture and momentum aperture of the candidate lattice is sufficient even when introducing errors (> $200\sigma_{x,y}$) to allow high efficiency on-axis injection and provide decent beam lifetime (see Fig. 3). The off-momentum frequency map for the ALS-II lattice is shown in Fig. 4.

Mitigation of the impact of the IBS effect on the equilibrium emittance of the ALS-II lattice will be achieved by operating the lattice with full coupling where the vertical emittance is given entirely by betatron coupling and by bunch lengthening using a 3rd harmonic RF system. This leads to smaller electron density and hence less IBS growth rates in emittance. A factor of 4 lengthening, as shown in Fig. 5, gives an emittance growth of less than 20% using passive 3rd harmonic cavity at 500 MHz fundamental RF system and 500 mA beam current [7].

The momentum acceptance of the ALS-II lattice is dominated by dynamic aperture which will result in small Touschek lifetime. On the other hand, bunch lengthening is powerful mean to combat this effect where the particles loss due to Touschek scattering events is less with less dense bunches. Touschek lifetime for the ALS-II ring of 1.2 hour has been achieved with 100% coupling, i.e round beam and long bunches at 500 mA beam current [8].

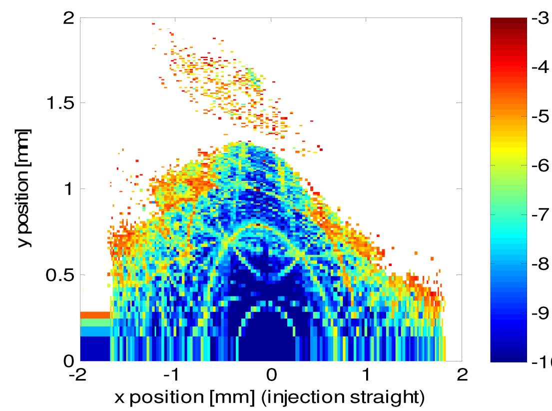

Figure 3: ALS-II lattice dynamic aperture with errors.

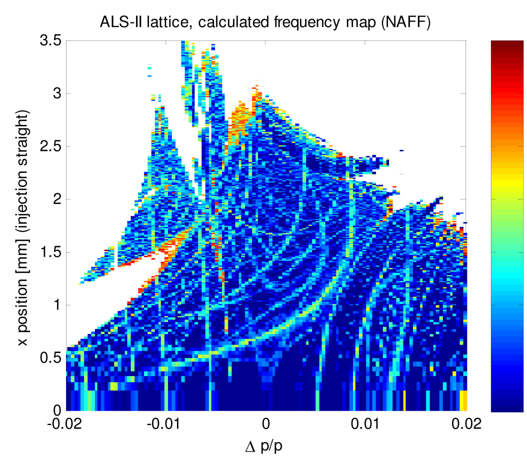

Figure 4: Dynamic momentum aperture of ALS-II candidate lattice.

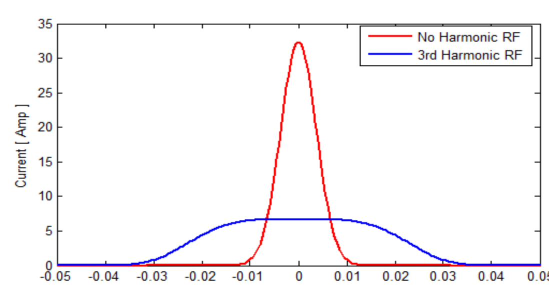

Figure 5: The bunch length of the standard and double RF system.

ON-AXIS INJECTION

The on-axis injection scheme is currently under study and it will be based on the swap-out scheme. A new accumulator ring will be built and housed either in the ALS storage ring tunnel or the booster tunnel. The

ISBN 978-3-95450-138-0

accumulator ring 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 the ALS-II ring. Figure 6 shows a candidate lattice for the accumulator ring that fits into the current booster tunnel with 78 m circumference and provides an emittance of 2 nm.rad at 2 GeV with sufficient dynamic aperture to allow for off-axis injection from the ALS booster, see Fig. 7. A partial swap-out injection into ALS-II ring is foreseen as a compromise between how fast the pulsed magnets systems for injection and extraction from the ALS-II ring and the accumulator ring vacuum and RF systems to accumulate the full current of the main ring in case of full swap-out option.

The partial swap-out option relaxes these requirements on the accumulator ring in terms of collective effects, RF power need and safety envelope of the current ALS shielding wall. Also partial swap-out helps to minimize the impact of injection transients. This is because only the fraction (say 10-20% of the full current) being swapped will have a larger emittance and thus a smaller brightness. Thus the brightness will decrease by the same factor and then recover in a few damping times (~20 ms). This small drop in brightness for a relatively short time compared with the time between swap-outs (~1 minute) makes swap-out virtually transparent to most of the users.

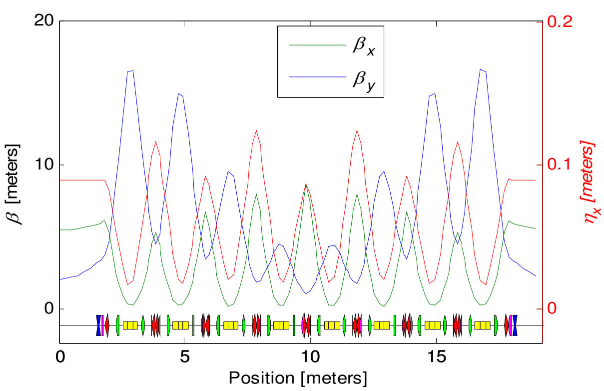

Figure 6: ALS Booster-size Accumulator ring lattice functions.

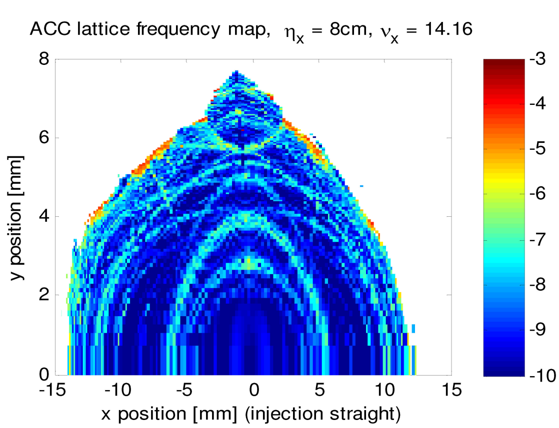

Figure 7: Accumulator ring dynamic aperture.

SUMMARY

The proposed baseline lattice for the ALS upgrade provides diffraction limited photon source up to 2 keV and fulfills the main constraints imposed by the fact that this upgrade is a replacement of the existing ALS storage ring. The lattice nonlinear effects are minimized by the proper configuration of the sextupole magnet families which results in a dynamic aperture sufficient for on-axis injection and lifetime with such strong focusing arrangement in one arc.

The use of double RF system to lengthen the bunches is powerful mean to mitigate IBS as a result strong focusing lattice and raise beam current threshold with decent Touschek lifetime.

Future work on achieving full coupling operation of the lattice and further optimization of the lattice momentum acceptance will be investigated. In addition studies of the injection process, fill pattern and accumulator ring choice need to be investigated to solidify the concept.

ACKNOWLEDGMENT

The Advanced Light Source is 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.

REFERENCES

[1] M. Bai et al., Nucl. Instr. and Meth. A (2010), doi:10.1016/j.nima.2010.01.045
[2] D. Einfeld, J. Schaper, M. Plesko, Design of diffraction limited light source, Proceedings of IEEE Particle Accelerator Conference, PAC95.
[3] J. Bjorken, S. K. Mtingwa, Proceeding of Particle Accelerator 13, 115 (1983).
[4] M. Borland, AIP Conference Proceedings 1234, 2009.
[5] L. Farvacque, et.al. A Low-Emittance Lattice for the ESRF, Proceedings of IPAC2013, Shanghai, China. MOPEA008.
[6] C. Sun, et al., Phys. Rev. STAB 15, 054001 (2012).
[7] J. M. Byrd, M. Georgsson. Physical Review ST Accelerator and Beams, 4(3) 092001 Sept. 2002.
[8] A. Piwinski, DESY 98-179, Nov. 1998. ISSN 0418-9833.