

STATUS OF THE APS UPGRADE PROJECT*

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Abstract

A concept for an upgrade to the Advanced Photon Source based on a multi-bend achromat lattice is being developed at Argonne National Laboratory. An MBA upgrade to the APS will reduce the horizontal emittance by a factor of ~ 50 . Coupled with superconducting undulators, the APS-U brightness will be two to three orders of magnitude beyond that which is available today at the APS.

INTRODUCTION

There is world-wide interest [1] in constructing 4th generation synchrotron radiation facilities with greatly reduced emittance based on multi-bend achromat (MBA) lattices [2]. MBA lattices promise to reduce the achievable horizontal emittance in electron storage rings by large factors, due to the favourable scaling of emittance [3] with the number of dipole magnets.

$$\mathcal{E}_x \propto \frac{E^2}{N_d^3} \quad (1)$$

Argonne National laboratory is developing a concept for a MBA upgrade to the Advanced Photon Source based on a multi-bend achromat lattice. This concept is the centerpiece of the Advanced Photon Source Upgrade Project (APS-U), which includes in addition to an upgrade to the storage ring, new insertion devices, front-ends and a suite of new and upgraded beamlines and associated optics and detector improvements.

APS-U CONCEPT AND PERFORMANCE

A conceptual design of the APS-U Project has been developed. The concept includes the following elements:

- A new 6 GeV MBA high-brightness storage ring in the existing APS tunnel
- Doubling of the ring stored beam current to 200 mA
- New insertion devices optimized for brightness and flux at the reduced storage ring energy
- New and upgraded beamline front-end systems of a common design for maximum flexibility
- A suite of new and upgraded beamlines designed for best-in-class performance with the high-brightness source
- Optics and detector improvements for remaining beamlines to take full advantage of MBA source properties
- Improved electron and photon stability

Table 1 compares the APS Upgrade storage ring design

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and performance parameters to those of the APS in present operation. The APS-U MBA lattice (described in more detail in [4]) is a seven-bend design based on the ESRF hybrid lattice concept [5]. The beam energy is reduced from the present 7 GeV to 6 GeV in order to further reduce the horizontal emittance. The beam current will be twice that which is routinely operated today.

Two operating modes are envisioned. The first mode is optimized for the highest possible brightness, and includes 324 regularly spaced bunches of 0.6 mA per bunch in a “flat-beam” configuration with 10% emittance coupling. A second mode – the timing mode – is optimized for a smaller number of equally spaced bunches with higher bunch current of 4.2 mA in a round-beam configuration with full emittance coupling to achieve an acceptable Touschek beam lifetime. The high-brightness mode achieves a horizontal emittance of 68 pm-rad, which is a factor of approximately 50 times smaller than present operation.

The brightness at 8 keV is a factor of 80 larger than today; the brightness at 20 keV is a factor of 340 larger than today, and that at 80 keV is a factor of 380 larger than today. The available coherent flux is higher by the same factors. The single bunch brightness is a factor of 25 greater than that achieved today.

Since the beam energy is reduced, undulator periods should be reduced accordingly to maintain similar first harmonic energies. In addition, APS-U will incorporate a suite of superconducting undulators, building upon recent developments of the last several years [6]. Front-ends will be upgraded to incorporate the recent High Heat Load Front-end concept that has been developed and successfully deployed at APS [7].

An MBA lattice at the APS opens new capabilities that don't exist today in coherence techniques with high energy x-rays. Beamline investments, through an open proposal process, will ensure international competitiveness of the beamline suite at the time of project completion and beyond. Targeted improvements to beamline optics are also incorporated into the concept to ensure that beamlines are positioned to take advantage of the MBA source properties.

Beam stability requirements are quite stringent [8]. Electron and photon stability requirements impact the engineering design at every level.

APS-U CONCEPTUAL DESIGN

Lattice

The APS-U lattice [4] is designed to optimize hard x-ray brightness by minimizing horizontal emittance in a MBA lattice. The lattice is composed of 40 identical sectors, each of which contains seven bending magnets.

Table 1: APS Upgrade Design and Performance Parameters

	APS MBA Timing Mode	APS MBA Brightness Mode	APS Now	Units
Beam Energy	6	6	7	GeV
Beam Current	200	200	100	mA
Number of Bunches	48	324	24	
Effective Emittance	47	68	3100	pm-rad
Emittance Ratio	1	0.1	0.013	
Horizontal Beam Size (rms)	18.1	21.8	274	μm
Horizontal Divergence (rms)	2.6	3.1	11.3	μrad
Vertical Beam Size (rms)	10.8	4.1	10.8	μm
Vertical Divergence (rms)	4.4	1.7	3.7	μrad
Stability of Beam Position/Angle	<10%	<10%	<10%	Fraction of beamsize/divergence
Brightness - 8 keV	78	130	1.5	10^{20} photons/sec/0.1%BW/mm ² /mrad ²
Brightness - 20 keV	90	203	0.6	10^{20} photons/sec/0.1%BW/mm ² /mrad ²
Brightness - 80 keV	3.3	7.9	0.02	10^{20} photons/sec/0.1%BW/mm ² /mrad ²
Pinhole Flux - 8 keV	221	246	55.5	10^{13} photons/sec in 0.5x0.5 mm ² pinhole at 30 m
Pinhole Flux - 20 keV	185	211	20.1	10^{13} photons/sec in 0.5x0.5 mm ² pinhole at 30 m
Pinhole Flux - 80 keV	6.6	7.6	0.7	10^{13} photons/sec in 0.5x0.5 mm ² pinhole at 30 m
Coherent Flux - 8 keV	466	781	9.30	10^{11} photons/sec
Coherent Flux - 20 keV	87	195	0.6	10^{11} photons/sec
Single Bunch brightness - 8 keV	162	40	6.4	10^{18} photons/sec/0.1%BW/mm ² /mrad ²
Single Bunch brightness - 20 keV	188	63	2.6	10^{18} photons/sec/0.1%BW/mm ² /mrad ²

The design was constrained to keep ID source locations approximately fixed. The lattice incorporates bends with vertical focusing to increase the horizontal damping partition number, and longitudinal gradient dipole magnets to further reduce the emittance [9]. The choice of beam energy was governed by competing effects. Reducing the energy below the present value of 7 GeV reduces emittance, but increases intra-beam scattering, enhances beam instabilities and decreases Touschek lifetime. On the other hand, higher beam energy requires higher bending fields and quadrupole gradients. The choice of 6 GeV balances these competing effects, and also provides the potential to double the stored beam current for similar RF power requirements. Intrabeam scattering and the reduction in Touschek lifetime are mitigated by operating with fully-coupled vertical and horizontal emittances in the high bunch charge mode, which in turn provides a better match to x-ray optical systems and also opens the possibility of incorporating insertion devices with round apertures, such as helical devices. Figure 1 shows a layout of the APS-U MBA lattice.

Injection

Due to strong non-linear fields, the dynamic acceptance of the lattice may preclude off-axis injection and

accumulation. Instead, storage ring injection and topoff are accomplished by a “swap-out” scheme in which individual stored beam bunches are removed and replaced on the same turn, directly on the closed orbit via a fast pulsed kicker system [10]. The combined kicker rise/flat-top/fall time must be shorter than twice the minimum inter-bunch spacing of 11.4 nsec. The stripline kicker system is driven by a pulser with requirements on rise/fall time of less than 4.5 nsec (10% to 90%) and flattop width of 5.9 ns for a 20 kV pulse [11, 12].

The APS injector system must be capable of providing a bunch charge up to 20 nC in order to replace one bunch in the 48-bunch operating mode. This requirement makes for a demanding performance requirement from the injector system. An R&D program [13] is underway to investigate and mitigate intensity limitations in the particle accumulator ring and booster synchrotron that limit present performance to 6 nC per bunch.

Vacuum System

The vacuum pumping strategy relies on a combination of aluminum extruded chambers with ante-chambers to accommodate mounted NEG strips, NEG-coated copper chambers and lumped pumping where possible. Detailed simulations of beam lifetime based on calculated pressure profiles are described in [14].



Figure 1: Layout of one APS-U sector. Dipole magnets are shown in red, quadrupole magnets in blue and sextupole magnets in yellow.

Magnet Systems [15]

Each sector contains seven dipoles, 16 quadrupoles and six sextupoles and four combined function fast corrector magnets for a total of 33 magnets of 11 distinct designs. There are four types of dipoles magnets, including two longitudinal gradient magnets and two transverse-gradient dipole magnets (“Q-bends”) which have quadrupolar fields through which the closed orbit traverses off-axis to generate a dipole field. There are four distinct quadrupole types, with operating gradients ranging from 48-99 T/m. Vanadium Permendur pole-tip material will be required on three of the four quadrupole types. Two distinct sextupole types are required. An 8-pole corrector is specified to provide horizontal and vertical dipole fields as well as a skew quadrupole field. The first pre-prototype longitudinal gradient dipole magnet has been constructed and assembled at Fermilab.

A critical aspect of the mechanical design is the achievement of very stringent alignment and stability tolerances, given nominal stability requirements of 10% on position and angle relative to beamsize and divergence. An R&D program is underway to construct a demonstration assembly consisting of pre-prototype quadrupole and sextupole magnets forming the “multiplet” section, mounted on a support base, mounted on a concrete plinth. This Demo Multiplet Module (DMM) will serve as a test-bed for alignment and stability studies.

An R&D program [16] is underway in a specially-instrumented sector in the present APS to correlate beam motion, BPM motion, floor motion and tunnel temperature, together with an orbit feedback system.

Harmonic Cavity System

A harmonic cavity system is incorporated in the design. This bunch lengthening system improves Touschek lifetime and mitigates intrabeam scattering [17]. The system uses a single-cell superconducting cavity based on the TESLA shape and operating at the 4th harmonic (1408 MHz) [18, 19].

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