The 2019 APS Accelerator Systems Strategic Plan

6.1 Introduction

The APS accelerator complex is the backbone of the APS scientific program. It includes a 7-GeV, 1.1-km storage ring operating with a 100-mA electron beam; a full energy booster synchrotron; a 400-MeV particle accumulator ring; a 400-MeV pulsed linac; and an S-band radio frequency (rf) thermionic electron gun. The APS has the largest installed 352-MHz CW rf power system in the U.S. and the second largest installed pulsed S-band rf power system. The APS uses over 1,500 power supplies to power various magnets, supports over 50 insertion devices, and utilizes numerous precision diagnostic devices to maintain beam quality.

Maintaining the high reliability of APS accelerator operations presents significant challenges. The accelerator systems continually undergo improvements directed at meeting new needs of scientific experiments. As already mentioned, the APS is in the midst of developing a technical design for a new storage ring using a MBA lattice. Replacing the existing storage ring with a new ring is foreseen early in the next decade and will result in a dramatic, two-to-three order of magnitude increase of the x-ray brightness. Careful provisions have been made in the Accelerator Systems Division (ASD) strategic plan to align current accelerator improvements and upgrades with the needs of a new ring, thus balancing requirements of current and future APS operations. The strategic plan is based on the following goals:

- Continue to operate the APS with excellent availability and beam quality
- Prepare the APS accelerator systems and staff for the APS Upgrade
- Pursue research in accelerator science and technology to benefit x-ray science

ASD 5-Year Strategic Plan

The APS and the ASD are reaching a critical stage with the planned decommissioning and removal of the current APS storage ring and installation of a new storage ring planned for mid-2022. Although the entire storage ring will have a completely new vacuum system, magnetic lattice, diagnostics, injection system, and power supplies, much of the existing accelerator infrastructure will remain in place. This includes the entire injector consisting of a 500 MeV linac, accumulator ring, and booster, the storage ring RF system, and refurbishment of some of the hybrid permanent magnet IDs. Our strategy for the next 5 years is guided by the following tenets:

- Maintain the highest reasonable availability for the current APS until the darktime
- Maintain, refurbish, and upgrade the existing accelerator complex that will not be replaced in the APS-U.
- Use the APS as a testbed for critical APS-U components and concepts when needed.
- Prepare the staff and facility for a rapid decommissioning of the current APS and a timely commissioning of APS-U.

Accelerator Reliability

The APS accelerator complex has been in operation for more than two decades. One of the challenges facing the ASD is maintaining reliable operation of the complex while preparing for the APS-U. Although the APS-U provides a new storage ring, the injector systems are undergoing relatively minor upgrades of individual components. By the time the APS-U is operational, much of the injector system will be over 25 years old, and in several cases using outdated technologies. The ASD will implement a plan to update as much of these systems as possible before the Upgrade without impacting operational reliability. The APS staff and management will ensure that this is done in the most cost-effective and efficient manner.

Through dedication to timely upgrades and rigorous maintenance protocols, the APS has become one of the world leaders in accelerator reliability with beam availability routinely above 98%. This requires continuous communication between technical staff and management to assess risks to reliable operation and to prioritize activities targeting high-risk issues.

For example, the APS linac, typically operated between 400-500 MeV, has much of the original control system developed in the early 1990s. It is becoming increasingly difficult to identify spares and replacement components for these parts. We are currently installing a linac rf test stand in an auxiliary building that will allow us to independently process rf components such as linac structures, waveguide windows, and SLAC energy doublers, and test new RF sources without impacting APS linac operations. This will also support development and commissioning of a modern linac controls system.

Accelerator Improvements

Magnetic Devices

The Magnetic Devices Group within the ASD is responsible for all APS magnetic systems, including over 45 undulator IDs, and is the world leader in superconducting undulator (SCU) development. The ASD continues to improve undulator performance, meeting challenges for the APS and other light sources in the DOE complex. Future work is focused on development of three-way-position revolver undulators, improving construction efficacy of hybrid IDs to meet technical and construction goals for the APS and the APS-U, development of automated ID magnetic tuning procedures, and development of a novel ID mechanical system that will allow faster gap change and better control of “strongback” deformations.

In preparation for mass production of hybrid IDs for the APS-U, special attention is being given to development of U.S. industrial partners to handle the majority of ID assembly external to the APS. The ASD continues to improve planar SCUs and is building a 3.5-m-long SCU with an extended “good field region” using NbTi wire and a thin vacuum chamber. A significant leap in SCU development will include the completion of NbTi SCU technology, and transfer of that technology to an industrial partner for SCU fabrication outside of the APS. The ASD is also designing SCUs using Nb_3Sn wire that provide even broader x-ray tuning ranges, and a high-temperature superconductor for a new generation of SCUs.

The ASD continues to advance the development of SCUs for polarization control. The next generation of polarizable sources is the SuperConducting Arbitrary Polarizing Emitter (SCAPE) that will be installed in the APS Upgrade (Figure 8). The SCAPE consists of horizontal and vertical undulators offset by a half period. By powering the coils in various configurations, the SCAPE can produce linear and elliptically polarized beams. One of the goals is to be able to switch helical polarizations at a rate greater than 10 Hz.

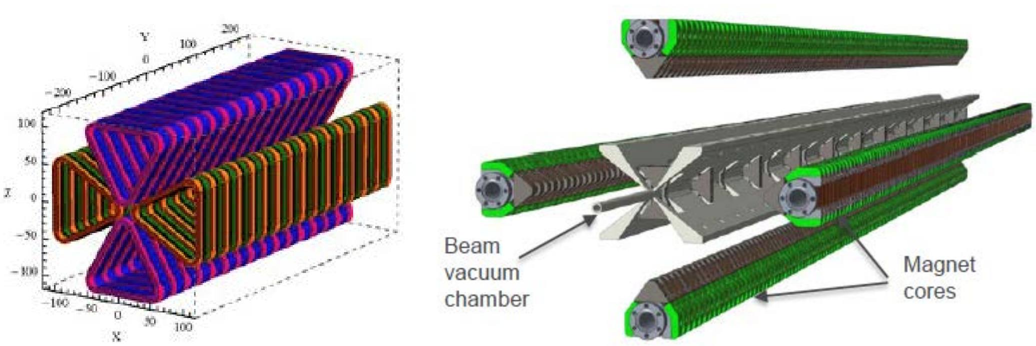


Figure 1. (Left) The Radia Model for the SCAPE SCU magnets. Horizontal and vertical fields are shifted by a half period and can be powered arbitrarily, allowing variable polarization. (Right) A mechanical drawing of the SCAPE assembly. The x-wing vacuum chamber allows extraction of heat generated by the beam.

Radio-Frequency Systems

The RF Group within the ASD maintains and improves the rf system reliability and lifetime for all of the APS accelerator systems by addressing aging, obsolescence, and performance issues, thus allowing the existing hardware to provide reliable performance up to the installation of the APS Upgrade and beyond. Specific attention is given to identifying and replacing weak and aging components, and to proactive maintenance of the 352-MHz storage ring rf systems.

One of the primary strategies for addressing obsolescence of the storage ring rf system is to transition from high-power klystron tubes to solid-state technology with the potential to provide higher efficiency, longer lifetime, and lower maintenance and ownership costs than traditional klystron power amplifiers. LDRD-funded research led to a successful in-house 8 kW prototype. We have now advanced to an industry 30 kW prototype that will allow testing of a final combiner configuration. If successful, the next step will be to work with industry to build a full-scale 200-kW rf station for installation and testing in the APS storage ring before the APS-U darktime. To ensure an adequate supply of 352-MHz klystrons during the transition to solid-state amplifiers, an effort is under way to secure a second klystron vendor (Figure 10).

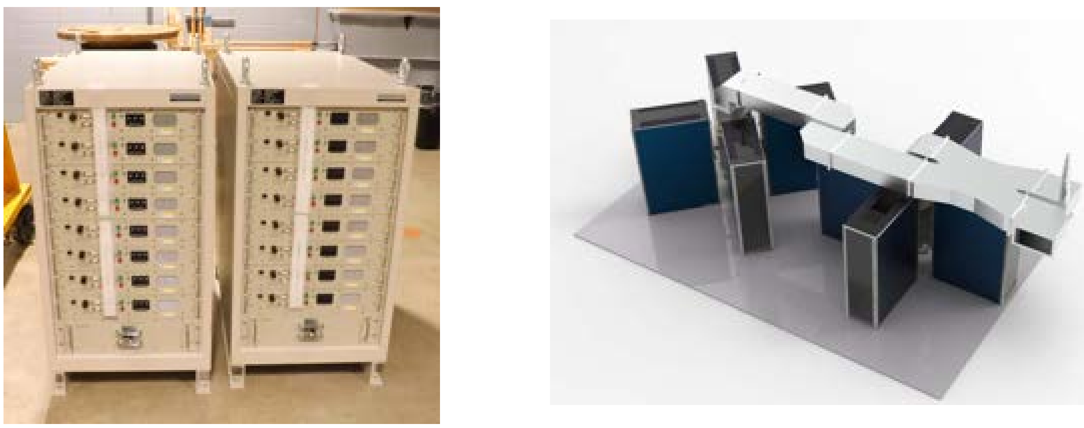


Figure 2. (Left) The first prototype 32 kW prototype solid-state amplifier received from R&K. (Right) The concept for a 200-kW amplifier. Each rack contains 15 2-kW amplifiers that are combined in the combiner cavity hidden below the waveguide. The first prototype amplifier will be tested on the combiner cavity later in 2019.

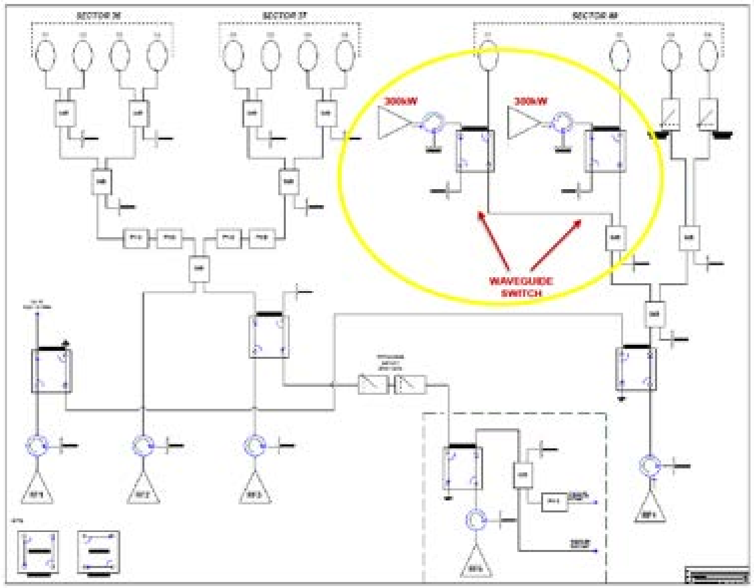


Figure 3. The transition plan to solid-state rf amplifiers will occur over approximately five years beginning from 2021. The schematic above shows the planned hybrid configuration of the rf system in 2023, following the APS-U installation.

Another area of emphasis is addressing obsolescence issues in the various rf systems in the APS storage ring and injectors. For example, the low-level rf controls will be upgraded to a modern digital system using a common platform. The ASD also maintains several rf test stands for testing components and developing new concepts. A 352-MHz rf test stand is utilized on a routine basis to condition and test new "green" tuners, couplers, and dampers in order to maintain a stock of conditioned and verified spare parts for the 352-MHz rf cavities.

Power Supplies

One of the critical functions of the ASD Power Supplies Group is in the area of power supply systems. The ASD will continue to identify and replace aging power supply hardware before it impacts operations. This will be achieved by continuing proactive maintenance, continuing the thermal imaging program to identify any overheating parts and electrical connections and repair them before an actual failure, and thoroughly testing all power supplies including stress tests during machine start-up before each user run to ensure reliability for operations. The ASD will continue to closely monitor the condition of power supply equipment during operations, and schedule repair and replacement during machine interventions for equipment that has shown signs of elevated temperatures, voltage ripples, and/or communication issues. Examples are rising temperatures of the aluminum electrolytic capacitors in power converters, and communication issues with power supply controllers caused by increased voltage ripples from the low-level-control power supplies. Obsolescence of a large number of components is a long-standing issue. Next in line is replacing the programmable logic controllers, the GESPAC power-supply controllers, and digital signal-processing controllers. Many commercial power supplies utilized in the injectors (particularly in the linac) are close to 30 years old. The ASD will replace those power supplies that are not supported by vendors. New commercial power supplies will not be 100% compatible with the original ones, so in-house solutions will be developed, in particular for many kicker power supply systems.

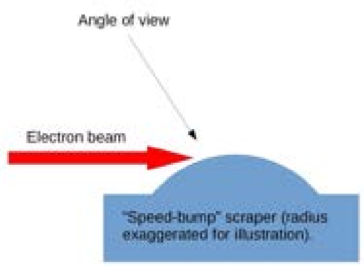
Beam Diagnostics

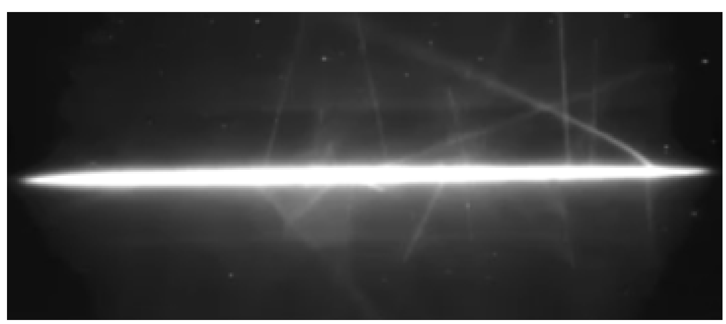
The ASD Diagnostics Group maintains and upgrades existing storage ring and injector diagnostics systems addressing aging, obsolescence, and performance issues that allow the hardware to provide reliable performance up to the APS-U "dark" (storage ring installation) period and beyond. More specifically, booster beam position monitors (BPMs) have been migrated to a field-programmable gate array (FPGA)-based system and particle accumulator ring BPMs with Libera SPARC electronics have been upgraded, as have obsolete BPMs and current monitors in the linac, transport lines, and linac extension area.

Accelerator Operations and Physics

The Accelerator Operations and Physics (AOP) Group within the ASD is responsible for managing reliable operation of the APS accelerator complex, and is the main source of accelerator physics theory and simulation to understand and improve the APS electron beams. The AOP stresses thorough automation of machine operation and analysis, since these are the keys to high reliability. For example, the AOP has improved real-time detection and monitoring of malfunctioning power supplies and BPM electronics to further enhance orbit stability by removing the malfunctioning devices quickly from the orbit feedback system in order to facilitate repairs. Other automation improvements include beam-dump analysis, injection optimization, and lattice and filling pattern switching. Other activities include improving operation of the bunch-by-bunch feedback system targeting via a reduced chromaticity in order to improve beam lifetime, in particular in a non-top-up, 324-bunch filling pattern where variation on the synchrotron radiation intensity with the decreasing current affects pointing stability in the users' beamlines.

One of the recent issues that has arisen as part of the preparations for the APS Upgrade is the effect of the impact of the APS-U beam on the various collimators that will be added to the vacuum system to protect the chamber. An analysis of a beam strike on a collimator has indicated that the beam power density is sufficiently high to raise the collimator material well above its melting point, essentially drilling through the material. A recent experiment was conducted by the AOP and Diagnostics group using the existing APS to further gain understanding of this phenomenon. During the experiment, the electron beam was focused to a smaller transverse size and directed onto a test collimator that was insertable into the beam. The collimator was externally imaged in real-time to observe the effect of beam impacts on either aluminum or titanium portions of the collimator. The setup is illustrated in Fig. xa where the beam has a glancing impact of the edge of the collimator. Shown is Fig. xb is a frame of the video recording corresponding to the beam impact. The glowing line is the light emitted from the glowing metal. Small ejecta are observed from the image. Shown in Fig xc is a postmortem cross sectional image of a strike on the aluminum collimator. The image clearly shows plastic flow of the metal after heating from the beam. We are continuing further experiments and analysis to understand this effect in detail.





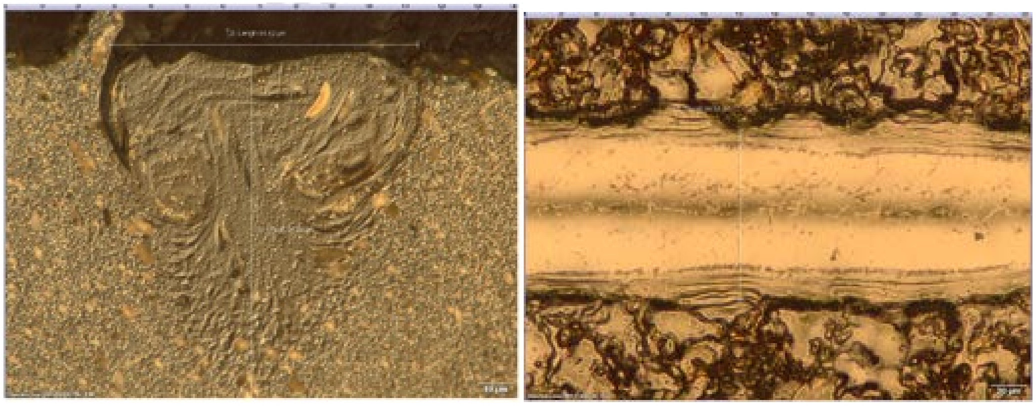


Fig X. a) A schematic layout of the collimator beam strike experiment. b) An image of the test collimator during a beam strike. Ejecta are observed as small flares from the molten metal. c) A postmortem metallurgical analysis showing the cross section of a beam strike region for Al. d) A top view of the beam strike "trough" formed on the Ti section of the collimator.

The ASD is a world-leader in modeling storage ring light sources with the continued development of the **`elegant`** code and a related suite of tools. The AOP continues improving and enhancing high-performance computing accelerator simulations while making these state-of-the-art codes available to the entire accelerator community, benefiting many accelerator facilities and projects beyond the APS and APS-U. Specific plans include increasing parallelization in simulation codes and SDDS tools; further development of a graphics processing, unit-based version of **`elegant`**; and continued benchmarking of single-particle and collective effects.

Accelerator R&D to Advance New Concepts and Next-Generation Light Sources

The APS has an earned reputation for staying on the cutting edge of accelerator science and technology that is beneficial for Argonne and the other DOE light source facilities. A suite of accelerator R&D programs focused on a versatile, cost effective, and energy efficient future light source ensures that the U.S. and the APS continue to maintain this competitive edge.

The APS core strategy is to perform high-impact accelerator research by concentrating on several key areas that maximize key APS strengths: sophisticated, high-fidelity simulation; development of advanced insertion devices; and innovative ideas for improved accelerator performance. While the main path forward focuses on a MBA lattice, opportunities also exist to explore whether the APS can supplement that with additional capabilities for use by specific user groups and for activities beyond the APS Upgrade.

Another component of the ASD strategic plan is innovative accelerator R&D advancing cutting-edge accelerator science and technology in the area of synchrotron light sources and other accelerator research areas beneficial for the greater accelerator community. The ASD has established leadership in several areas of interest to future light sources including:

- Nb_3Sn Super Conducting Undulators: We are developing the first full scale device based on Nb_3Sn wire with a promise of 30% higher field vs NbTi SCUs. Testing of a 0.5 m prototype is underway with the goal of installing a 5.2 m cryostat containing dual 2.x m SCUs prior to the APS-U darktime.

- Cavity-based X-ray Free Electron Lasers: With the advent of the high repetition rate XFELs such as the LCLS-II, several schemes for improving the longitudinal coherence of the x-rays have appeared based on resonating the x-rays in an optical cavity based on high-purity diamond mirrors. A collaboration between Argonne and SLAC has formed with the 3-year goal of building an optical cavity and demonstrating it on LCLS-I with anticipated use on LCLS-II when available.

- High average brightness photoinjectors: Argonne is exploring the possibility of adopting the Superconducting RF gun originally developed at the University of Wisconsin and completing the demonstration and characterization of this gun.