ALS Accelerator Operations and Improvements FY21–FY24

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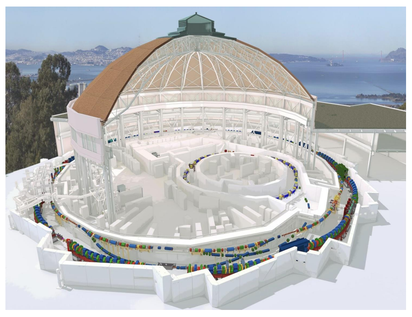
ALS ADVANCED LIGHT SOURCE

Abstract

The LBNL Advanced Light Source, a pioneering third-generation soft x-ray synchrotron radiation source operating at 1.89 GeV with a 2-nm beam emittance, stands as one of the earliest facilities in its class, continually evolving to maintain its status at the forefront of soft x-ray sources.



As a mature facility, the ALS is entering a new era requiring reliable high-quality operations, support for ALS-U installation activities, and space for ALS-U component testing (see dedicated poster). This poster summarizes the accelerator complex and key parameters, presents operational statistics for FY21–FY24, and highlights recent advancements in the accelerator's hardware and software infrastructure.

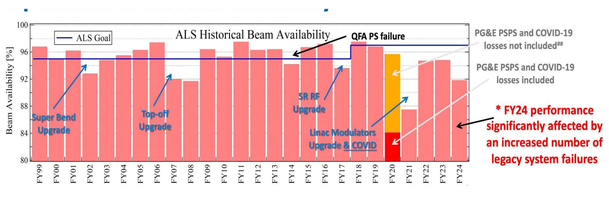
Accelerator Overview

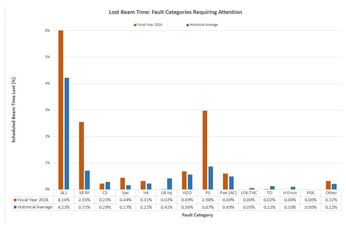
- **Linear Accelerator**: S-band (3 GHz) 50 MeV linac for initial electron acceleration from therm. gun
- **Booster Ring**: operates at 0.7-Hz cycle, elevates electron energy to full storage ring energy
- **Storage Ring (SR)**: operates at 1.89 GeV in continuous topoff with a 12-cell detuned triple-bend achromat and super-period 3 (see Table 1)
- **Beamlines**: 40+ experimental beamlines deriving from 14 insertion devices and bend magnets (6 hard x-ray source points in superbends), annually serving over 1,500 users
- **Insertion Devices (IDs)**: 7 elliptically polarizing undulators (EPUs) enabling full polarization control of the photon beam in canted straights, 2 in-vacuum undulators, 4 planar undulators, 1 wiggler

Table 1: Advanced Light Source storage-ring parameters

Beam energy	1.89 GeV
Circumference	196.8 m
Beam current	500 mA
Top-off beam current variation	≤ 0.3%
Radio frequency	499.64 MHz
Emittance H/V	2.0 / 0.04 nm·rad

Operational Statistics





Several quality indicator parameters are used.
DOE requires a **Performance Measure Manager**
PMM > 90%

DOE Metrics
$$PMM = \frac{Delivered\ hours\ at\ the\ FY\ end}{Originally\ targeted\ hours\ for\ the\ FY}$$

Fiscal Year	FY Goal Hours	Delivered Hours	Bonus Users Hours	DOE PMM (%)
FY21	3168	2910	92	94.8
FY22	4000	3831	126.0	98.9
FY23	3880	3606	157.1	97.0
FY24	2952	2845	174.2	102.3

At ALS we target a **Facility Availability Performance** FAP > 97%,
a **Mean Time Between Failure** MTBF > 50 hours and a **Mean Time To Recover** MTTR) < 90 min

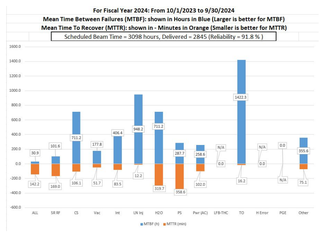
Users' operation reduced from the "typical" 5,000 hours to install the ALS-U Accumulator

Fiscal Year	Scheduled Hours	Delivered Hours	FAP (%)	MTBF (hours)	MTTR (min)
FY21	3327	2910	87.5	43.8	382
FY22	4046	3831	94.7	41.2	84
FY23	3804	3606	94.8	51.4	161
FY24	3098	2845	91.8	30.9	142

Linac Modulators Upgrade & COVID

ALS Internal Metrics
$$FAP = \frac{Delivered\ hours}{Actual\ scheduled\ hours}$$

Increased number of legacy accelerator

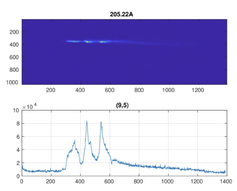


Storage Ring & Injector Systems Development

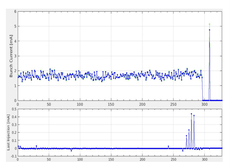
- **Injector System:** a multi-year plan is underway to modernize RF systems and amplifiers, and enhance linac timing distribution and booster RF amplifiers (see dedicated poster).
- **Storage Ring RF System:** major 2021 upgrade included new dual 300-kW 500-MHz CW klystrons for improved flexibility and reliability. Enhancements included new waveguide switchyard and replacing aging high-power water loads with high-performance ferrite-lined loads to support future device additions (see dedicated poster).
- **Storage Ring Global Realignment:** entire ALS storage ring was realigned in FY21 according to most recent survey data. New golden orbit defined accordingly via global beam-based alignment with resulting minimal perturbations to photon trajectories. Beamlines were re-aligned where necessary. Mean corrector magnet excitation was reduced substantially.

Beam Dynamics

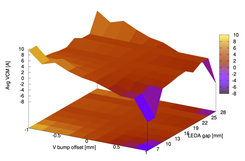
- Developed always-online **linac energy measurement** based on scintillator image analysis and dispersive BPM data.



- **First-turn threading** developed exploiting TxT capability of the turn-synchronized ALS BPMs in single pass mode along with user-friendly high-level application for monitoring & data acquisition.
- **New fill pattern**: a new method of injecting in topoff resulted in major improvement of fill pattern homogeneity (impacting diagnostics), rendering ALS more resilient against injector fluctuations & tuning transients.



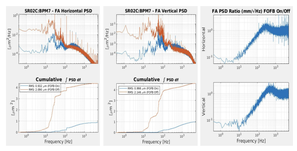
- **ML/AI applications** in support of ALS operational improvements as well as design & modeling optimization (see dedicated poster).
- **In-situ field mapping with beam** has been developed & employed to investigate and quantify damage to the magnetics of a 4.5-mm gap in-vacuum undulator that is restricting dynamic aperture and lifetime.



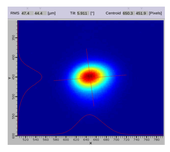
- Working point scans & **permanent shift of horizontal tune** implemented to raise injection efficiency when damaged in-vacuum undulator closes to very small gaps. **Local skew quad compensation** has been developed & feed-forward implemented to reduce adverse effects of this device at small vertical gaps.

Diagnostics

- **BPMs**: precision in ALS beam position measurement was enhanced by replacing 175 BPM electronics throughout the storage ring and injector. Integration with orbit feedbacks and pilot tone calibration has significantly improved measurement accuracy.
- **Fast Orbit Feedback System**: the FOFB system was upgraded with new BPMs and cell controller hardware supporting 10 kHz throughput, significantly enhancing ALS stability & performance. Installation of new Caen PSs & replacement of vacuum chamber spools have improved rms orbit stability tenfold at low frequencies (image courtesy G. Portmann).



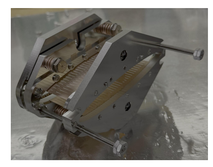
- **Multi-bunch Feedback System**: multi-bunch FB system has seen major upgrades enhancing both transverse and longitudinal diagnostics. This included new transverse amplifiers & longitudinal iGp unit, improving instability damping, beam dynamics analysis, and diagnostic capabilities.
- **Diagnostic Beamlines**: upgrades to diagnostic beamlines 3.1 & 7.2 involved replacing legacy components with advanced digital systems, LYSO scintillators & adding fast-gated cameras. This has significantly enhanced operational efficiency and data quality for turn-by-turn analysis. Recently improved filtering at BL3.1 has lowered the required gain and thereby substantially improved 10-Hz readout noise dynamic range.



Insertion Devices & Vacuum Systems

- Recent additions include **38-mm EPU** for COSMIC beamline and **15-mm in-vacuum undulator** LEDA for GEMINI beamline, boosting photon production & expanding scientific capabilities with a focus on high-energy operations critical for biological research (see dedicated poster).

- In FY21 all legacy **ion pump controllers** in the ALS storage ring were replaced with compact, modern units. Upgrades improved reliability and allowed for electronic rack consolidation, freeing up space for new components dedicated to ALS-U.
- Various aging **flexbands** (in-vacuum RF shields for bellows) have been exchanged in an effort to restore design acceptance (lowering radiation dose) & reduce RF heating during topoff ops.



- Legacy **ion pumps** replaced in various sections of the accelerator complex, most recently all ion pumps in the SR RF section (SR03 straight).

Other Software Development

- **Control System**: the ALS has significantly upgraded its control systems, transitioning to a fully EPICS-based system implementing Linux virtual machines.
- **Timing System**: extension and improvements to the ALS timing system and enhanced with in-house developed high-speed digitizers supporting advanced RFSoC data acquisition.
- **High-Level Applications**: ALS has introduced several high-level applications, including multiple feedback systems for beam stability and synchronization, and machine learning algorithms for dynamic beam size control and stabilization. These improvements have notably enhanced operational flexibility, stability, and precision in beam control.
- **Control System Development Environment:** transitioned to Control System Studio (Phoebus) for high-level GUI development and converted legacy control room displays (EDM, C#, QT).

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