DESIGN AND INTEGRATION OF ALS-U STORAGE RING MODULES

D. Gudkov, F. Matichard, A. Talon, C. Espino Devine, C. J. Valdez, E. Newman,
J. Shaw, J. Osborn, M. Holmes, M. F. Khalid, S. Myers, T. Peev
Lawrence Berkeley National Laboratory, Berkeley, CA, United States

Abstract

The Advanced Light Source Upgrade (ALS-U) is an ongoing project at Berkeley Lab to transform the ALS into a fourth-generation synchrotron light source. To minimize the ALS users facility down time, the ALS-U Storage Ring (SR) is composed of 48 unique, highly integrated modules, each split into approximately 11 subsystems. Thousands of unique physical interfaces are distributed across the modules and between modules, facilities and beamlines.

This contribution presents how the complex interfaces have been managed using interface control documentation and tailored interface verification methods based on a combination of Computer-Aided Design (CAD) assemblies and dedicated prototypes. These tools were adopted to manage both module-level integration and external interfaces with facility infrastructure and beamlines to mitigate integration risks. To validate the design solutions a physical 1:1 mockup has been developed alongside the CAD models.

The combined CAD-mockup validation approach revealed critical issues not detectable through CAD only, including cables' installation feasibility problems that would have caused redesign work and significant delays. The physical mockup also enabled more accurate analysis of maintenance access, assembly process and electrical safety. The practical experience from SR modules design in facility/beamlines integration context, methodology evolution during the design process, and recommendations for similar accelerator upgrade projects are also presented.

INTRODUCTION

Reducing the beam emittance for ALS-U to improve the coherent flux requires a complete replacement of the existing storage ring (SR) by introducing a multi-bend achromat (MBA) lattice [1]. The new SR lattice is a nine bend achromat with reverse bends and features 384 magnets divided across 12 sectors.

These sectors comprise a total of 48 unique modules, each housing between 6 and 10 magnets. A general view of a module is shown in Fig. 1. In addition to magnets (3 in Fig. 1), the modules include other components such as support structures (1), alignment systems (2), vacuum systems (4), beam diagnostics (9), water cooling (5) using low-conductivity water (LCW), and compressed air (8) systems. Control electronics (7) are located near the controlled devices. The modules house survey and alignment (S&A) target nests (10) and approximately 200 short-haul cables with an associated cable management system (6).

The available design volume and external interfaces are defined by the existing tunnel configuration, the multitude of ALS beamline front-ends [2], and the proximity of the new transfer lines. The compactness of the systems, combined with limited available volume and a complex operational contextrequires a rigorous interface management process using CAD models, design structure matrices (DSM), interface control checklists (ICC), and physical mockups.

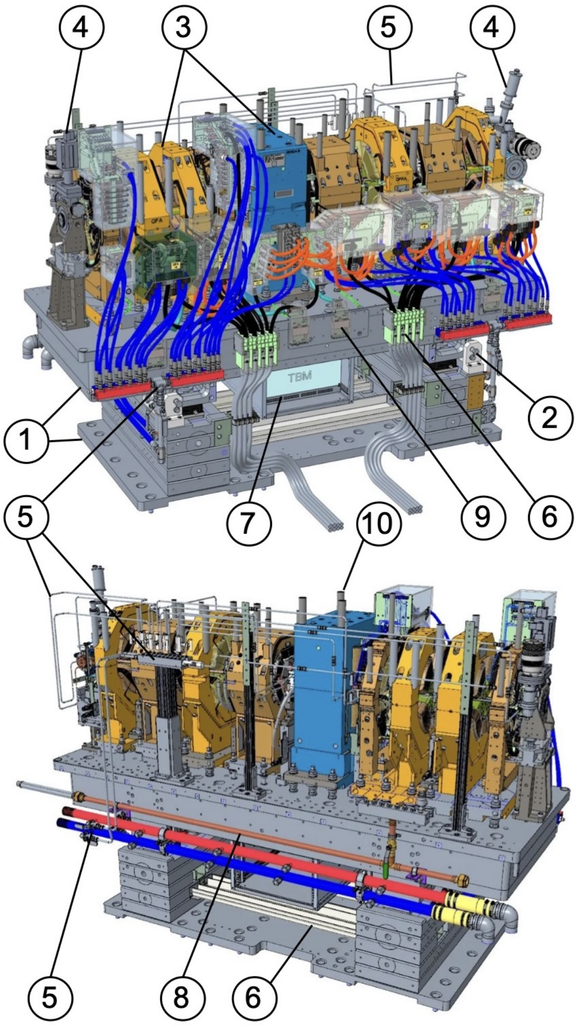


Figure 1: SR Module General View.

SR MODULES DESIGN OVERVIEW

Design Data Management

The Parametric CAD system, paired with the Product Lifecycle Management (PLM) system, are used for designing the SR and managing documentation. Figure 2 illustrates the interrelationships of design data as defined in the PLM system for the SR modules. An Item is the data entity that constitutes the formal definition of a module, serving as the central hub for all engineering, manufacturing, and lifecycle data required to produce and manage that module throughout its lifecycle.

The SR module-level design data is structured to simplify interface and fabrication management. Components for each subsystem (mechanical or electrical) are grouped into assemblies regardless of their physical distribution within a module assembly. While the subsystem child assemblies and components do not necessarily physically connect, this logical structuring significantly simplifies data preparation for component kitting, as it guarantees an exact, one-to-one alignment between the CAD BOMs and the physical kit BOMs used by manufacturing.

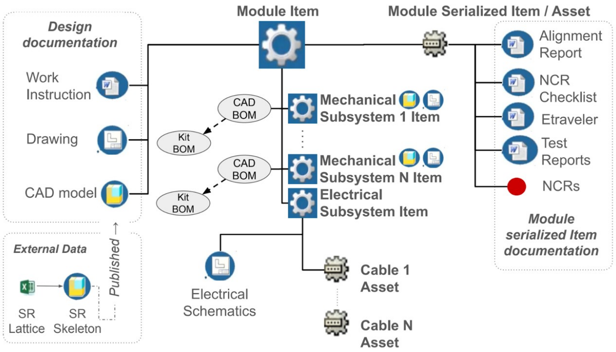


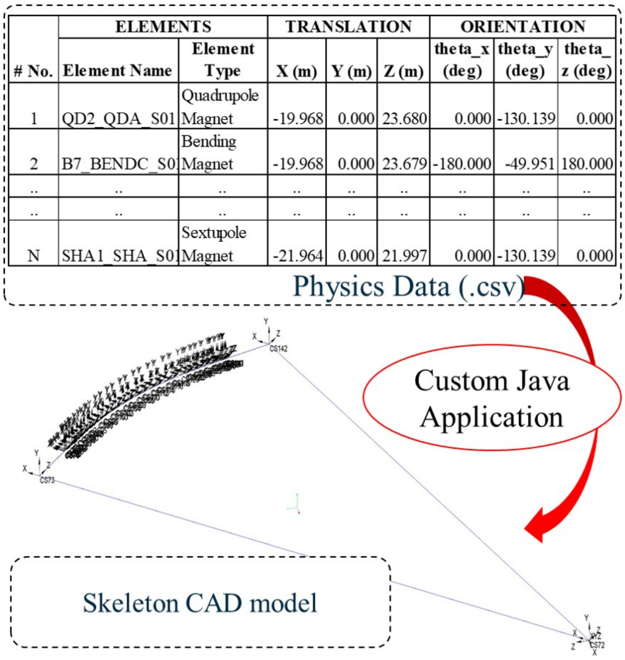
Figure 2: SR Module Design Data Structure.

Modeling short-haul cables would require significant effort for relatively little return. Therefore, their routing is illustrated on electrical schematic drawing [3]. These drawings and individual cable instances are attached to the Electrical subsystem Items. Serialized items, or assets are generated for each physical module. These objects store all documentation related to a specific module instance, such as Non-Conformity Reports (NCRs), e-travelers, alignment reports, and other quality control or fabrication documents.

Lattice Skeleton Model for Magnets Positioning

Magnet positioning plays a critical role in the design of the SR modules. Any change in magnet position propagates through most of the systems on the SR. To maintain traceability to the lattice and ensure error-free positioning across different CAD models, a SR skeleton CAD model associated with the lattice file is utilized. This model contains the magnets coordinate system defined by the lattice parameters. It acts as the master control structure for the design, driving the placement of magnets in the model. The magnets' coordinate systems match up with the coordinate systems on the SR skeleton model, guaranteeing positioning accuracy. The process for creating the skeleton is shown in Fig. 3.

To provide skeleton coordinate systems at the module assembly level, the required objects are published top-down from the SR skeleton model. The magnet coordinate systems define the primary boundary for the module integration model. Other systems are added to the model subsequently; these must not affect magnet positions and must remain within the external boundary of the model.



# No.	ELEMENTS		TRANSLATION			ORIENTATION		
	Element Name	Element Type	X (m)	Y (m)	Z (m)	theta_x (deg)	theta_y (deg)	theta_z (deg)
1	QD2_QDA_S01	Quadrupole Magnet	-19.968	0.000	23.680	0.000	-130.139	0.000
2	B7_BENDC_S01	Bending Magnet	-19.968	0.000	23.679	-180.000	-49.951	180.000
..	..	..	..	..	..	..	..	..
..	..	..	..	..	..	..	..	..
N	SHA1_SHA_S01	Sextupole Magnet	-21.964	0.000	21.997	0.000	-130.139	0.000

Figure 3: Data Flow for creating Skeleton CAD model.

INTERFACE MANAGEMENT

Interfaces Identification

In parallel with the CAD integration activities, internal and external interfaces are jointly defined by the subsystems owners, under the coordination of the systems engineering. Figure 4 shows a Design Structure Matrix (DSM) mapping all interfaces. Each cell contains letters annotating the interface types: Mechanical (M), Electrical (E), and Information (I). For example, because cabling is mechanically fixed to the support/alignment subsystem, a mechanical interface is present between these two subsystems. These interfaces represent the design context and must be verified using interface CAD models that encompass all involved subsystems.

Design Interfaces Verification

Each interface is described by a CAD model and an interface document. These documents provide descriptions of the interfacing systems, requirements, and a verification checklist.

The latter serves as the basis for the Interface Control Checklist (ICC), a tool used to verify interfaces across all SR modules. The ICC consists of a series of questions to investigate any geometric interferences or a mismatch in other parameters, such as incompatible materials.

Magnets Power Cables Rerouting Following the Interface Verification

A notable example of the usefulness of these tools was the decision to reroute magnet power cables due to heating issues identified during the design phase. These cables were initially routed in close proximity to the ”raft” (the plane supporting the magnets). Because these cables transport significant current, they also generate significantheat.

Interface Control Checklist Raft Level	Supports/Alignment	Vacuum	Cabling	Facilities Integration	LCW - Raft	Magnets	Instrumentation + Diagnostics	Controls	Beam Front-ends	Compressed air	Survey & Alignment
Supports/Alignment											
Vacuum	M										
Cabling	M	M, E									
Facilities Integration	M										
LCW - Raft	M	M		M							
Magnets	M	M	M, E		M						
Instrumentation + Diagnostics	M	M, E, I	E								
Controls	M		E			E, I					
Beamline front-ends		M	E	M	M						
Compressed air	M	M		M							
Survey & Alignment	M					M					

M Mechanical
E Electrical
I Information (Data)

Figure 4: ALS-U SR Module Design Structure Matrix.

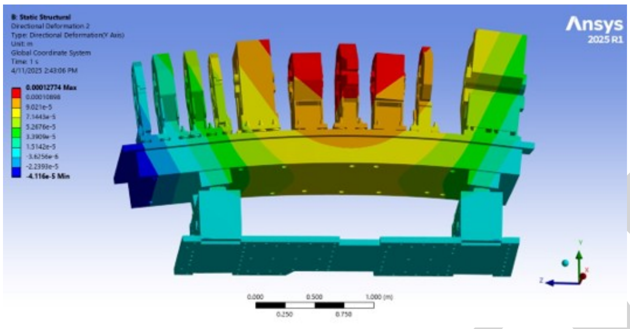


Figure 5: Magnets misalignment illustration due to cables heating (max Y magnitude is 98 µm).

It was identified that the trapped heat between the raft and control racks could present a thermal deformation problem, bowing the raft and moving magnets beyond the alignment tolerance (see Fig. 5). Identifying this interface early allowed for a rerouting decision, avoiding a much more expensive redesign later when the change would have propagated through other systems.

Mockup Prototype Interface Verification

While these digital tools provide reliable interface verification, a CAD model alone cannot account for every physical nuance of the SR module. Consequently, there is a residual risk of overlooking issues related to interference, assembly, or installation. The ALS-U mechanical systems and integration team utilized a cost-effective 1:1 mockup to verify remaining interfaces and incorporate feedback into the SR module design. The mockup also allowed for a feasibility analysis of assembly and maintenance processes (Fig. 6).

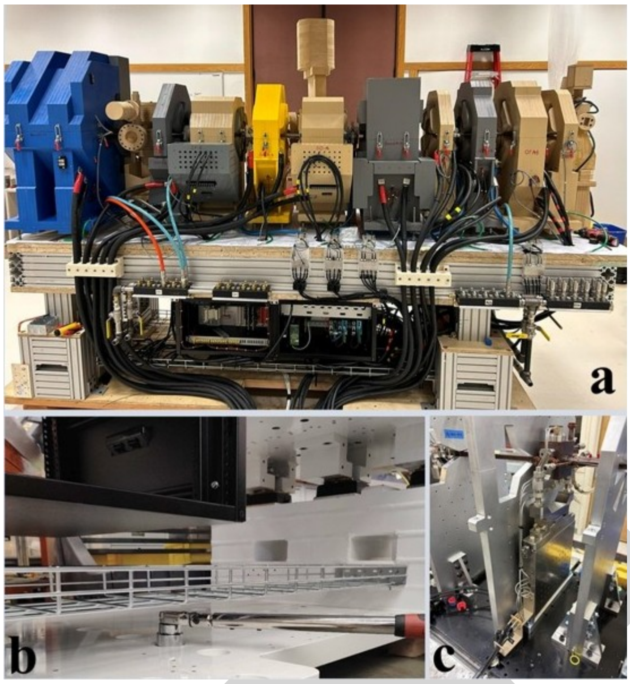


Figure 6: SR Module Mockups for interface verification: (a) mockup, (b) electrical cable tray integration, (c) vacuum chamber test fits.

CONCLUSION

The design and integration of the complex ALS-U SR modules demonstrate the necessity of a rigorous, multi-tool interface management strategy for accelerator upgrades in existing and compact facilities. To reduce the risks of integration and installation issues, a combination of interface management tools have been tailored to this application.These were critical for establishing structured data management, ensuring precise traceability for magnet positioning via lattice skeletons, and mapping thousands of mechanical, electrical, and information interfaces. In addition, relying solely on digital systems can leave residual risks regarding the integration of distributed systems in highly integrated assemblies. Coupling digital data management with physical mockups provides a holistic validation model that can uncover hidden physical interferences, prevent costly late-stage redesigns, and optimize downstream assembly, installation, and maintenance. This combined methodology can help considerably reduce integration risks in similar large-scale systems.

REFERENCES

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