SWISS LIGHT SOURCE 2.0 VACUUM SYSTEM CONDITIONING AND FIRST YEAR OF OPERATION

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Abstract

After more than two decades of user operation, the Swiss Light Source (SLS) entered a major upgrade phase in October 2023, targeting a 40-fold reduction of electron-beam emittance via a new 7-bend achromat lattice at 2.7 GeV. The vacuum system, central to machine performance, was completely rebuilt to meet the stringent requirements imposed by the compact lattice. The new storage ring vacuum consists of an 18 mm aperture, 288 m long system assembled from over 500 chambers. Following 14 months of installation, first beam was achieved in January 2025. Vacuum conditioning represented a critical milestone, enabling delivery of light, with nominal beam current, to the first experiments in April. This contribution presents the vacuum conditioning of the SLS 2.0 storage ring during this first year of operation, from initial commissioning to user operation.

INTRODUCTION

The SLS at the Paul Scherrer Institut (PSI) started user operation in June 2001 and delivered ≈5000 h of user beam time per year at 98.5% availability [1]. The emergence of diffraction-limited storage rings (DLSRs) based on multi-bend achromat (MBA) lattices motivated the SLS 2.0 upgrade project. The new ring replaces the 12-fold triple-bend-achromat (3BA) with a 12-fold 7BA lattice achieving a natural horizontal emittance of 150 pm rad at 2.7 GeV – within the existing 288 m tunnel [2, 3]. Vacuum system undergone complete re-design to match the new magnetic array.

The 14-month dark period began in October 2023. The beam commissioning started in January 2025; the first stored beam was obtained four weeks later; 400 mA was first achieved in April 2025 [4].

VACUUM SYSTEM DESIGN

The twelve 7BA arcs each span ≈18 m and contain continuous vacuum chamber strings with the following key parameters [5,6]: (i) 18 mm inner diameter electron channel – four times smaller cross-sectional area than SLS 1.0; (ii) OFE-Cu walls (steel for chambers located in Fast-Steering magnets) of minimum 1 mm thickness; (iii) 500 nm Ti-Zr-V NEG coating, baked and activated ex-situ to ≈10^{-11} mbar before installation; (iv) seven active pumping blocks per arc containing ion pump (Diode, 55 l/s); NEG cartridge pump (Capacitorr Z400); and (v) glidcop (Cu - Al) crotch absorbers handling up to 3.7 kW per standard bend [5].

Straight sections contain a mix of new and old vacuum components connected to the arc strings via tapered transitions.

VACUUM CONDITIONING (JANUARY–AUGUST 2025)

Arc Conditioning Curve

The normalised average dynamic pressure rise $\mathrm{d}P/I$ [mbar/mA] was computed from stable beam periods of minimum 2 h after subtracting static base pressure. Figure 1 shows the conditioning curve versus accumulated beam dose. The initial scrubbing phase was interrupted by frequent beam dumps; nevertheless, a clear downward trend became apparent as commissioning progressed. After 100 Ah, the design target $\mathrm{d}P/I = 2 \times 10^{-12}$ mbar/mA was reached in April 2025, demonstrating the effectiveness of NEG coating and its ex-situ activation.

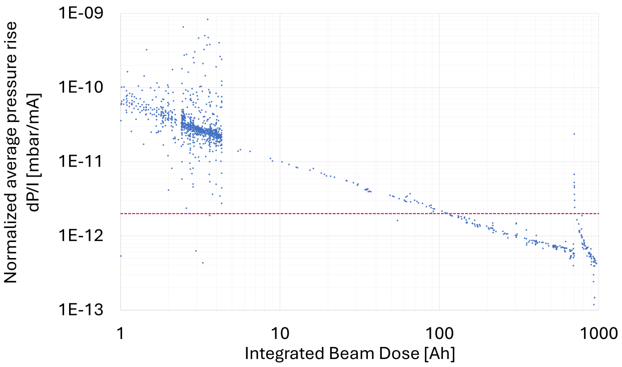

Figure 1: Normalised average pressure rise $\mathrm{d}P/I$ [mbar/mA] vs. accumulated beam dose [Ah] for SLS 2.0. Design target 2×10^{-12} mbar/mA (pink line) reached at ≈100 Ah. The September 2025 ID installation and subsequent recovery are visible above 500 Ah.

Residual Gas Analysis

The ring is equipped with four RGAs, located above crotch absorbers. Figure 2 shows spectra from four representative sectors. In the best-conditioned sectors (e.g. Sector 11), H_2 is the dominant species, confirming effective NEG pumping of reactive gases. Sector 1 exhibits anomalous CH_4 and Argon peaks attributed to residuals of an abrasive cleaning brush found inside the crotch absorbers. It can also indicate a small air leak. Sector 8 shows elevated H_2O and CO/N_2 from less-conditioned straight-section components.

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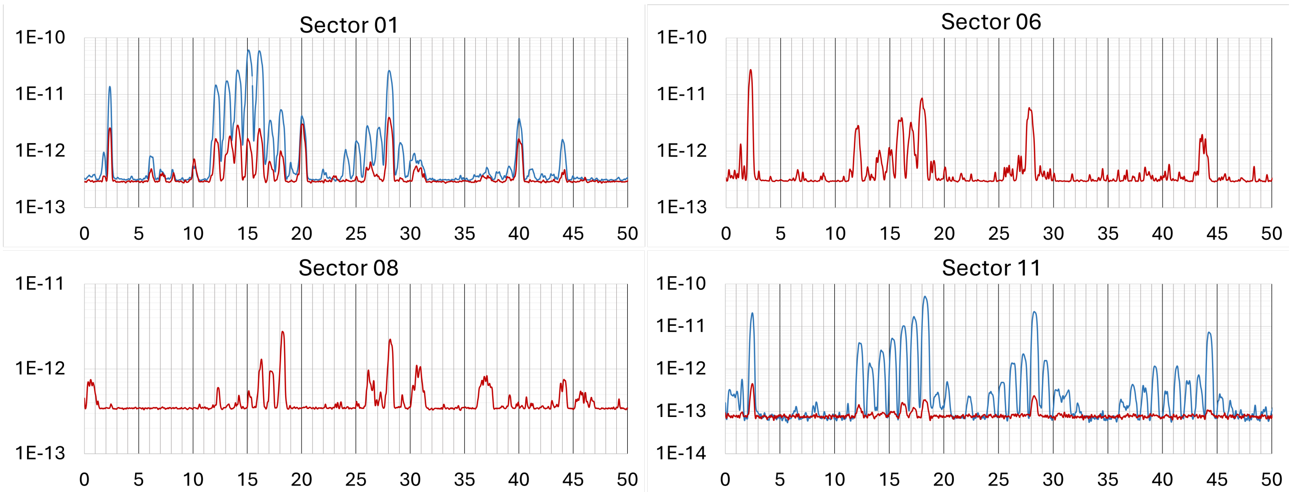

Figure 2: RGA mass spectra from Sectors 01, 06, 08, and 11 in February (blue line) and in November at 400 mA (red line). X-axis: Atomic Mass Unit [AMU]; Y-axis: Ion Current [A].

Thermal Monitoring

Each chamber is instrumented with multiple type-K thermocouples enabling early detection of thermal anomalies. Examples include (i) a front-end gate valve reaching >60 °C from a disconnected pneumatic actuator; (ii) SiC HOM plugs on corrector kickers overheating before dedicated cooling was retrofitted.

Moreover, the measurements enabled validation of finite element method (FEM) thermal simulations and estimation of thermally induced mechanical stress in the vessel walls. Based on these results, corrective actions were applied to the cooling circuits to mitigate the risk of thermally driven failure.

INSERTION DEVICE INSTALLATION (SEPTEMBER 2025)

Two new insertion devices (IDs) were installed in September 2025. The **UE36 Apple-X** soft X-ray undulator featuring a 2 m-long aluminium chamber of 9 mm aperture with NEG coating. The **U15 in-vacuum undulator** consisting of aluminum cubes enclosing over 2000 internal parts, including a copper foil for RF-shielding. The Pre-installation pump-down revealed unacceptable contaminants pressure levels traced to insufficiently cleaned externally procured components. The device was disassembled, all parts were individually cleaned and reinstalled.

Both installations caused the beam lifetime to fall from ≈10 h to ≈2 h and forced a reduction in stored current to 300 mA. An unscheduled intervention replaced the UE36–arc matching section with a larger-aperture assembly of increased pumping speed.

LOW-TEMPERATURE BAKEOUT

Strategy

The initial intervention did not bring significant improvement in beam lifetime. The IDs beam scrubbing is inherently slower than arc conditioning per unit of accumulated charge: the specific photon dose deposited in the straights is far lower than in the arc dipoles, as seen in Fig. 3. An in-situ low-temperature (limited by the maximum temperature allowed on permanent magnets) bakeout was therefore applied during the October 2025 shutdown. Two procedures were developed to protect permanent-magnet arrays and fragile chambers:

- **UE36**: hot water at 140 °C circulated through the existing cooling circuit for 10 days, with the undulator gap open to isolate the magnet arrays.
- **U15**: resistive heater tapes on aluminum undulator body at 80 °C , rising to 120 °C at pump blocks and tapers and 300 °C at adjacent NEG cartridges for reactivation.

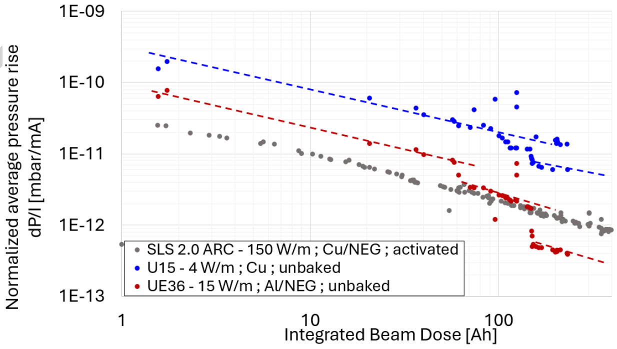

Figure 3: Normalised dynamic pressure rise dP/I vs. integrated beam dose for: SLS 2.0 arc, U15 and UE36. The bakeout produces a clear step improvement for both ID sections.

Results

Following the intervention, all key metrics recovered within ≈200 Ah: beam lifetime returned to 9 h; vertical beam size decreased from 17 µm to 13.5 µm; and the dynamic pressure trajectory rejoined the expected conditioning curve. By end of 2025, first light had been delivered to twelve beamlines.

PHASE 2 OUTLOOK (2026)

Phase 2 installations in 2026 will introduce further vacuum system modifications. The replacement of two permanent 2 T superbend dipoles with superconducting 5 T dipoles requires venting and ex-situ reactivation of the affected 18 m arc strings. Three hard X-ray U17 undulator, an extended version of the U15 installed in September 2025, will be assembled from individually cleaned, baked, and UHV-acceptance-tested components. For the soft X-ray UE36 and UE38 undulators, a revised installation procedure employing neon venting followed by hot-water bakeout and NEG cartridge reactivation is foreseen to minimise conditioning time and ensure prompt recovery of beam quality.

CONCLUSION

SLS 2.0 achieved the design dynamic pressure rise of 2×10^{-12} mbar/mA at 400 mA within 100 Ah of beam dose, confirming the effectiveness of ex-situ NEG activation. Residual gas spectra confirmed H_2 dominance in conditioned sectors. Insertion-device installation in September 2025 revealed the critical importance of formal UHV cleanliness acceptance for vendor-supplied in-vacuum components. Low-temperature in-situ bakeout at 80 °C to 140 °C proved an effective and magnet-safe recovery strategy, restoring nominal performance within 200 Ah. Phase 2 installations in 2026 will build systematically on these lessons.

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