Status of TLS and TPS Accelerators

Taiwan Light Source (TLS)

Machine Parameters of the TLS

The Taiwan Light Source (TLS) celebrated its 30th anniversary of first light in 2023. Having provided light source services for 32 years since it began operation in 1993, TLS has invited experimental proposals and opened its facilities to users, initially featuring three soft X-ray beamlines: HSGM, LSGM, and Seya. The original TLS design was based on a triple bend achromat lattice with a beam energy of 1.3 GeV and a beam current of 200 mA. Following several phases of upgrades, the accelerators now achieve a beam energy of 1.5 GeV, a maximum stored beam current of 360 mA, top-up injection, a superconducting radio-frequency (SRF) cavity, a liquid-helium cryogenic system, superconducting wigglers (SCWs), and advanced feedback systems for orbit and bunch-to-bunch stability. Many of these advancements were pioneering and unique in the low-energy synchrotron community. The key parameters of TLS are presented in **Table 1**.

Table 1: Main parameters of the TLS storage ring.

Beam Energy (GeV)	1.5
Number of Buckets	200
Current (mA)	360
Horizontal Emittance (nm-rad.)	22
Vertical Emittance (pm-rad.)	88
Tunes (ν_x/ν_y)	7.303/4.175
Lifetime (hour)	> 6

The storage ring, designed with sixfold symmetry, features four room-temperature undulators, one wiggler, and five SCWs, giving TLS the most densely packed SCW configuration in the community. SCWs generate high-energy photons to support X-ray users. The specifications of the insertion devices are detailed in **Table 2**.

Table 2: Main parameters of the insertion devices used in TLS.

	W200	U50	U90	EPU56	SWLS	SW60	IASWA	IASWB	IASWC
Type	Hybrid	Hybrid	Hybrid	Pure	SC	SC	SC	SC	SC
Period Length (mm)	200	50	90	56	250	60	61	61	61
Photon Energy (eV)	800–15k	60–1.5k	5–500	80–1.4k	2k–38k	5k–20k	5k–20k	5k–23k	5k–20k

Statistics of TLS Machine Operation

During the initial top-up injection phase, the stored beam current was limited to 200 mA in early 2005 due to constraints of the RF system capabilities and beam stability. Following the installation of the SRF module and the upgrade of the feedback system, TLS gradually increased the stored beam current to 360 mA after 2010. **Figure 1** presents the performance metrics of TLS operations from 2011 to 2025. Availability is defined as the ratio of actual user time to scheduled user time; mean time between failures (MTBF) is defined as the ratio of scheduled user time to the number of system faults; and the beam stability index is evaluated based on photon intensity variation in the diagnostic beamline, maintained within 0.1%.

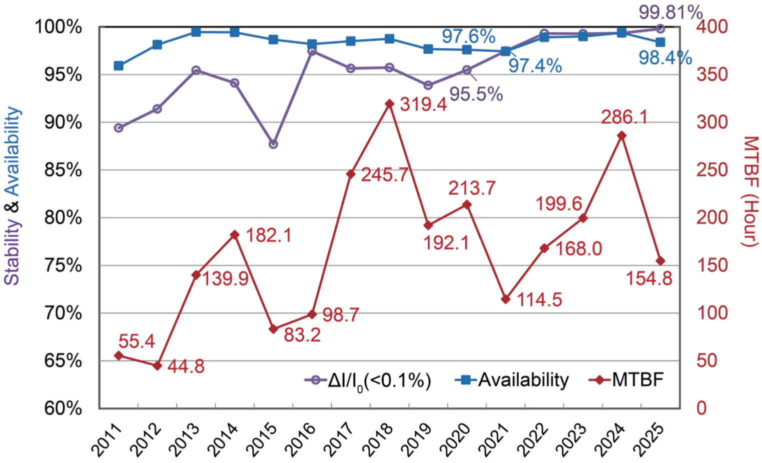

Fig. 1: Annual beam stability index of 0.1%, availability, and MTBF for the TLS.

In 2025, the annual availability of TLS reached 98.4%, with scheduled user time totaling 4,488 hours, an MTBF of 154.76 hours, and beam stability of 99.81%. The primary reason for the low MTBF this year was six abnormal voltage sag events from Taiwan Power Company (TPC), occurring once in March, three times in April, and twice in November. These voltage sags caused damage to high-voltage-sensitive critical subsystems, which triggered multiple beam trips.

Downtime and Failure Analysis of the TLS

In 2025, there were 28 beam trips and a total of 72.02 hours of downtime. The SRF system, which provides high power to the stored beam and operates at 4.5 K, is complex and requires a strict interlock protection system. This system accounted for the largest portion of the annual downtime but has a fast recovery time. **Figures 2 and 3** summarize the contributions of each subsystem to the overall performance of the TLS facility. The primary causes of downtime this year were six force majeure voltage drops, where three events in April were particularly impactful. These voltage drops induced six consecutive trips of the unstable pulser power supplies during injection operations. Additionally, five emergency power feeder phase-loss incidents in late November and December led to four RF system trips and an extended recovery period. These events highlight the need to evaluate the replacement of aging infrastructure and to strengthen power grid stability to ensure reliable operation in the future.

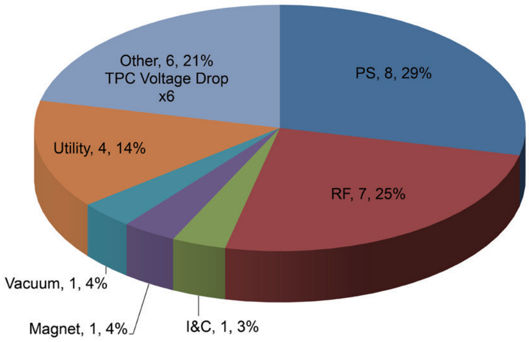

Fig. 2: Proportions of beam trips for the TLS accelerators in 2025 (28 trip events in total). The labels in the pie chart indicate the subsystem, number of events, and percentage, respectively. PS: power system; RF: radio frequency; I&C: instrumentation and control. "Other" includes 6 voltage drops caused by TPC.

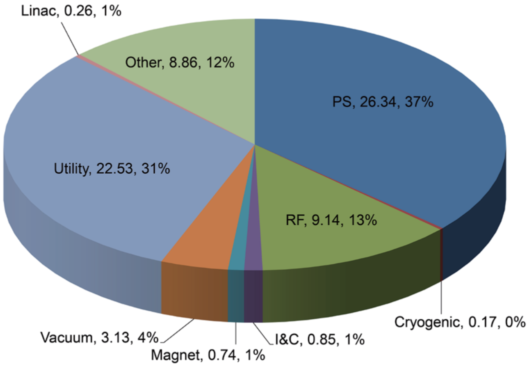

Fig. 3: Downtime distribution for the TLS accelerators in 2025 totaled 72.02 hours. The major sources of failure were: PS, 26.34 hours; Utility, 22.53 hours; RF, 9.14 hours; and Other, 8.86 hours.

Taiwan Photon Source (TPS)

Machine Parameters of the TPS

The TPS has been operational for nine years, having officially opened to user proposals in 2016. The TPS storage ring uses a strong focusing DBA lattice, which provides low emittance, top-up injection, SRF module operation, long straight sections, and high stability. The main parameters of the TPS storage ring for current operation are listed in **Table 3**. The TPS accelerators consist of concentric storage rings and booster rings within the same tunnel, a design chosen due to limited campus space and energy requirements.

Table 3: Main parameters of the TPS storage ring.

Beam Energy (GeV)	3
Circumference (m)	518.4
Current (mA)	500
Number of Buckets	864
Beam Emittance ($\varepsilon_x/\varepsilon_y$) (nm-rad.)	1.6/0.016
Momentum Compaction (α_1/α_2)	0.0024/0.0021
Tunes (ν_x/ν_y)	26.15/14.23
Lifetime (hour)	> 8

Statistics of TPS Machine Operation

The TPS began operations for users in the last quarter of 2016 with a beam current of 300 mA. This was increased to 400 mA in December 2017, and the system continued to operate regularly until it reached 450 mA on the last day of 2020. In 2021, the stored beam current reached 500 mA. To meet the needs of user experiments, we now provide both hybrid mode and uniform filling mode operation at a total current of 500 mA. In hybrid mode, 560 tightly packed electron bunches are placed in the storage ring along with one isolated high-charge single bunch in the remaining gap. This configuration supports both high-current/high-flux multi-bunch experiments and time-resolved measurements using the single bunch (**Fig. 4(a)**, see next page). Conversely, in uniform filling mode, the electrons are evenly distributed around the ring, typically with 800 or more bunches, resulting in a smooth and stable beam current profile that benefits high-current and steady photon-flux applications (**Fig. 4(b)**).

The scheduled and delivered user times, along with availability, are shown in **Fig. 5** on a quarter-to-quarter basis since 2017. For 2025, the scheduled user time is 4,904 hours, of which 1,968 hours will be operated in uniform filling mode. The annual availability of TPS reached 98.7%, with a highest MTBF of 222.9 hours, as shown in **Fig. 6**.

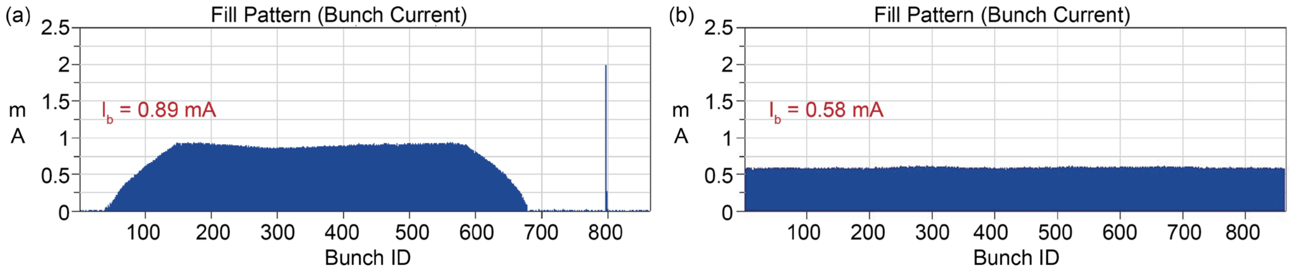

Fig. 4: (a) Hybrid mode and (b) uniform filling mode operation.

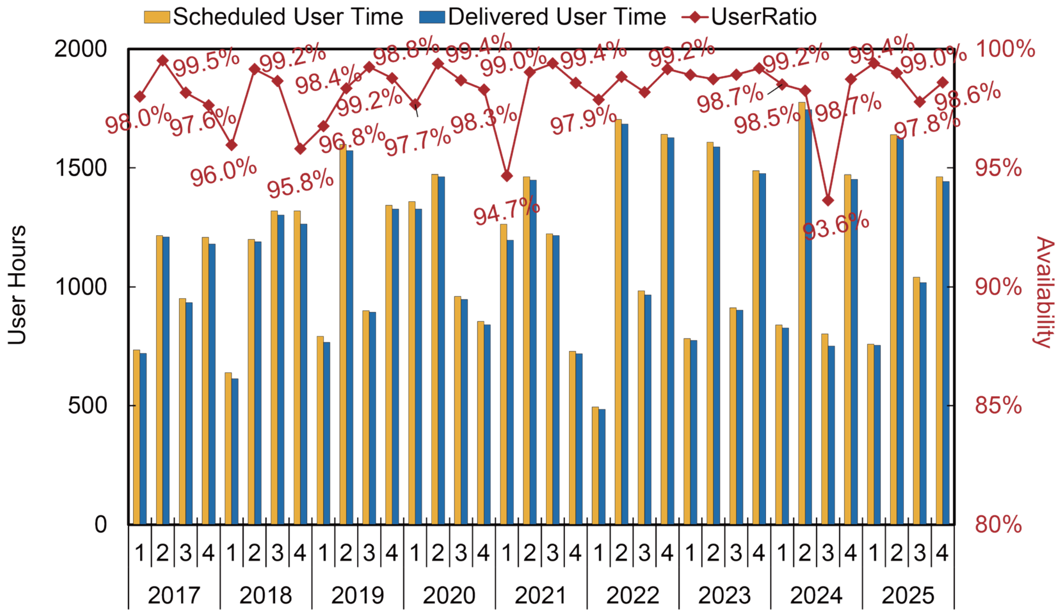

Fig. 5: User time and beam availability at the TPS from 2017 onward.

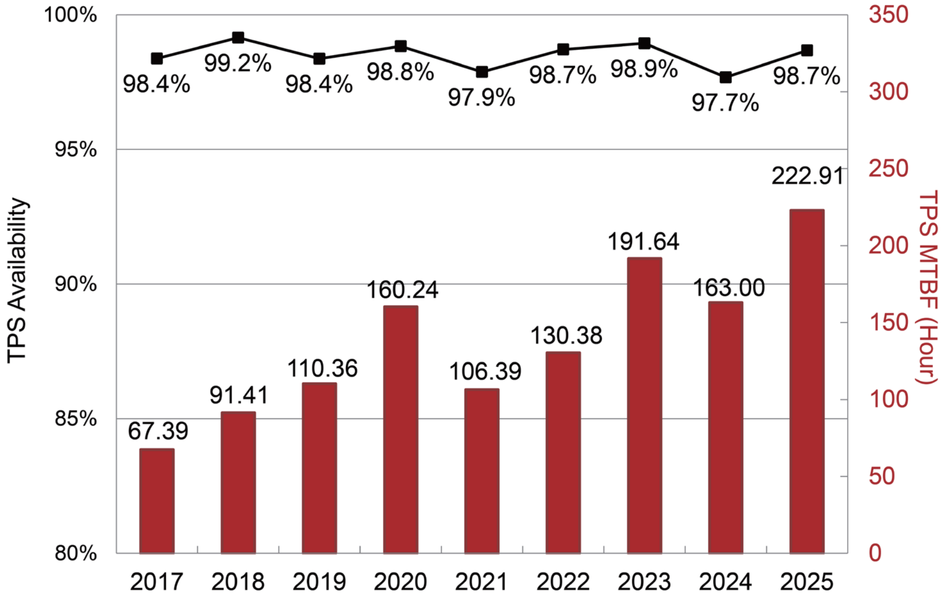

Fig. 6: MTBF and beam availability at TPS from 2017 onward.

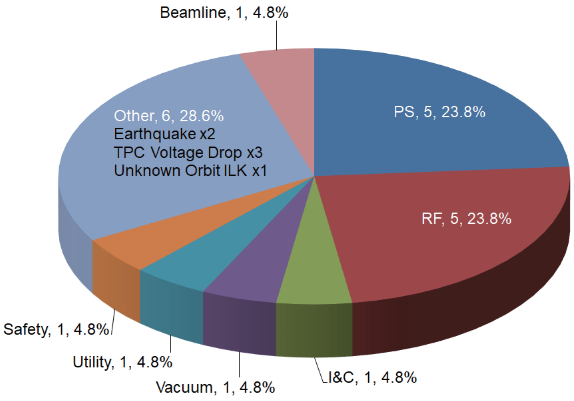

Fig. 7: Ratios of beam trips for the TPS accelerators in 2025 (21 trip events in total).

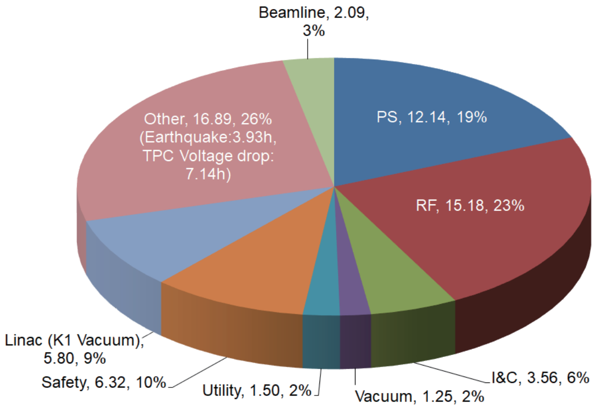

Fig. 8: Proportions of downtime in the TPS accelerators in 2025 (64.73 hours in total). The major downtime contributors are as follows: RF, 15.18 hours; Other, 16.89 hours; PS, 12.14 hours; and Safety, 6.32 hours.

Downtime and Failure Analysis of the TPS

In 2025, there were 21 beam trips and a total of 64.73 hours of downtime. **Figures 7 and 8** illustrate the contributions of each subsystem within the TPS facility to these beam trips and downtime. The PS and SRF subsystems were the most frequently involved in these incidents. The higher failure rate of the SRF system is attributed to sensor aging, solid-state module damage, and cooling system leakage, all resulting from prolonged operation at a high current of 500 mA. Nevertheless, excluding trips caused by earthquakes and unexpected voltage drops by TPC, the overall reliability of these subsystems has significantly improved in recent years, enabling stable operation and extending the MTBF. (Reported by Hung-Jen Tsai)

Feasibility Study for TPS Upgrade: 6BA Solution

The Taiwan Photon Source (TPS) has been in successful user operation since 2016, delivering high-brightness synchrotron radiation source for diverse scientific purposes. Considering that the typical lifecycle of a storage-ring light source is 20–30 years, NSRRC has initiated a feasibility study for upgrading TPS to a next-generation, referred to as TPS-II.

Motivation and Design Concept

TPS is a 3 GeV, 518.4 m storage ring housed in a common shielding tunnel with its booster. It provides synchrotron radiation spanning from soft to hard X-rays, achieving a peak brightness of approximately 10^{21} photons/s-mm^2-mrad^2-0.1%BW at 10 keV. While the primary objective of the upgrade is to enhance scientific capabilities, energy sustainability is also a key motivation. The new lattice aims to reduce beam emittance by at least tenfold compared to TPS, resulting in an order-of-magnitude increase in its brightness and coherence fraction. This would allow for shorter sampling times, higher data throughput, and more efficient experiments.

The study focuses on an upgrade constrained by the existing tunnel. The tangential angle of all beamlines must remain unchanged to preserve the utility of existing experimental hutches. The straight sections must remain longer than 5 m to accommodate current insertion devices and RF modules. This compact design necessitates combined-function magnets, compact beam position monitors, and Non-Evaporable Getter (NEG)-coated vacuum chambers. Permanent magnets are planned for use in the arcs, which would not only create essential space for vacuum and diagnostic components but also significantly reduce power consumption. To maintain operational flexibility, the quadrupoles adjacent to the straight sections and the multipoles along the ring will remain electromagnets. Additionally, to ensure beamline performance, longitudinal-gradient bends— in which the center field is higher— are incorporated at the specified angle. This study follows the successful third- to fourth-generation upgrades, such as ESRF-EBS,[1] APS-U,[2] and SLS 2.0,[3] which adopted the MBA[4] or HMBA[5] concepts.