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 its first operation in 2023. Since its commissioning 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 achromatic lattice with a beam energy of 1.3 GeV and a beam current of 200 mA. Following several phases of upgrades, the accelerator has now achieved a beam energy of 1.5 GeV, a maximum stored beam current of 360 mA, top-up injection capabilities, 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, which is designed with sixfold symmetry, features four room-temperature undulators, one wiggler, and five SCWs, giving resulting in the most densely packed SCW configuration in the community for the TLS. SCWs enable the generation of high-energy photons to support X-ray users. The specifications of the insertion devices are listed in **Table 2**.

Table 2: Main parameters of the insertion devices used in the 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 because of the constraints of the radio frequency 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 2024. 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%.

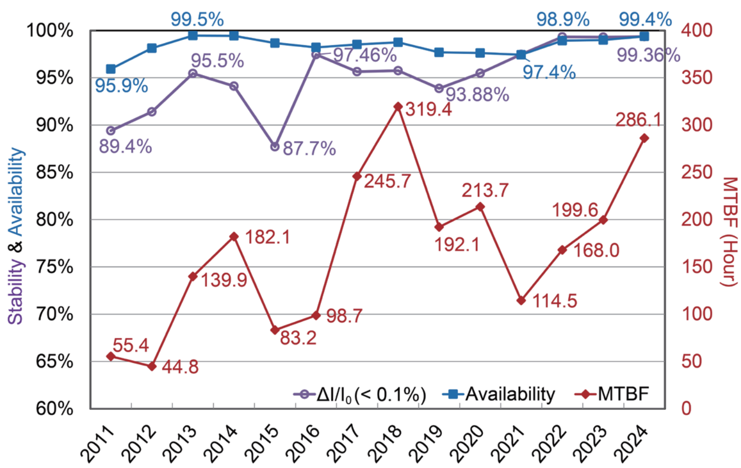

Fig. 1: Annual beam stability index of 0.1%, availability, and MTBF of the TLS.

In 2024, the annual availability of the TLS reached 99.4%, with scheduled user time totaling 4,578 hours, a second-highest MTBF of 286.1 hours, and a beam stability of 99.36%. After switching of the pulsed klystron supplier from Thales to Canon in 2023, the operational reliability and stability of the TLS linear accelerator system have significantly improved in 2024.

Downtime and Failure Analysis of the TLS

In 2024, there were 15 beam trips and a total of 28.35 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 with a fast recovery time. The contributions from each subsystem of the TLS facility are shown in **Figs. 2 and 3**. The primary causes of downtime were force majeure and unknown events, including earthquakes and voltage drops at the power station. The second-most common cause of downtime was related to the instrumentation and control group (I&C), including issues such as FOFB, failures in the power supply of the 500 MHz master clock RF amplifier, and ILC failures. Alternative solutions for replacing failed and aging systems are currently being evaluated.

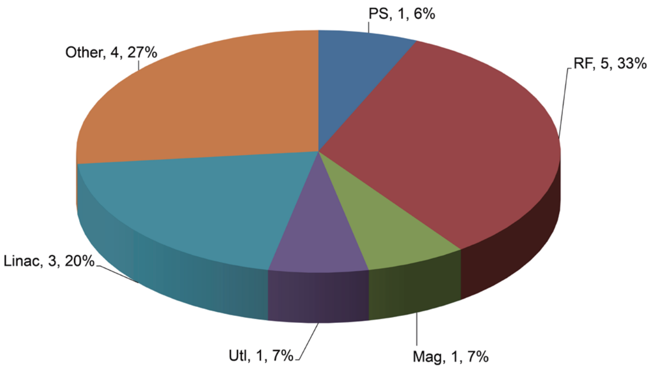

Fig. 2: Proportions of beam trips for the TLS accelerators in 2024 (15 trip events in total). RF stands for radio frequency; PS stands for power supply; and I&C stands for instrumentation & control. "Other" includes 1 earthquake, 1 voltage drop caused by Taiwan Power Company (TPC), and 2 unknown partial beam losses.

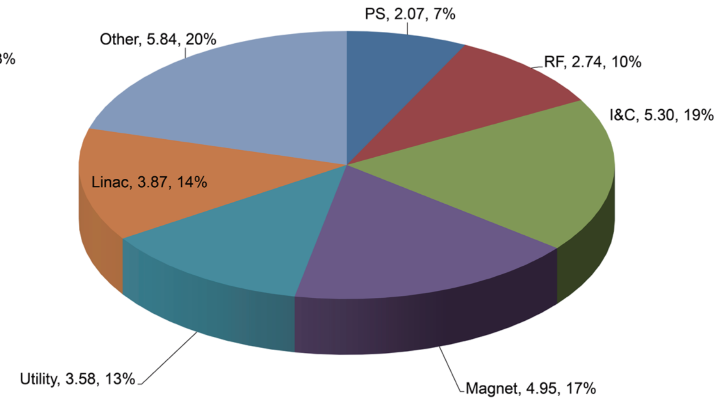

Fig. 3: Downtime distribution for the TLS accelerators in 2024 (totaling 28.35 hours). The major failure times were as follows: other, 5.84 hours; I&C, 5.3 hours; magnet, 4.95 hours; and Linac, 3.87 hours.

Taiwan Photon Source (TPS)

Machine Parameters of the TPS

The Taiwan Photon Source (TPS) has been operational for eight years, having officially been opened to users in 2016. The TPS storage ring incorporates a strong focusing double bend achromatic lattice, which features low emittance, top-up injection, SRF module operation, long straight sections, and high stability. The major 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 choice made considering the limited space on the campus and energy conservation.

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, which increased to 400 mA in December 2017. The system continued to operate regularly until it reached 450 mA on the last day of 2020. In 2021, the stored beam current reached an operating current of 500 mA. The COVID-19 pandemic caused delays in the delivery of several key components for the Phase-II and Phase-III beamlines. Despite these challenges, through dedicated collaboration between vendors and NSRRC staff, 18 beamlines were available for user operation in 2024.

Figure 4 on the next page shows the scheduled and delivered user times and availability on a quarter-to-quarter basis since 2017. The scheduled user time in 2024 was 4,890 hours. Because of frequent earthquakes in Hualien from April to May, a total of 8 beam trips and a recovery time of 12.01 hours were recorded. As shown in **Fig. 5** on the next page, the annual availabilities with and without seismic induction statistics were 97.7% and 97.92%, and MTBF of 163 hours and 221.2 hours, respectively.

Downtime and Failure Analysis of the TPS

In 2024, there were 29 beam trips and a total downtime of 113.36 hours. With the 8 beam trips caused by earthquakes excluded, the contributions of each subsystem within the TPS facility to these beam trips and downtime are illustrated in **Figs. 6 and 7**. The subsystems most frequently involved in beam trips and downtime are the SRF and LINAC systems. The higher failure rate of the SRF system is attributed to sensor aging and solid-state module damage resulting from prolonged operation at a high current of 500 mA. For the LINAC system, the primary issue is the long recovery time caused by klystron failure. Nevertheless, excluding trips caused by earthquakes, the overall reliability of these subsystems has significantly improved in recent years, enabling stable operation and extending the MTBF. (Reported by Hung-Jen Tsai)

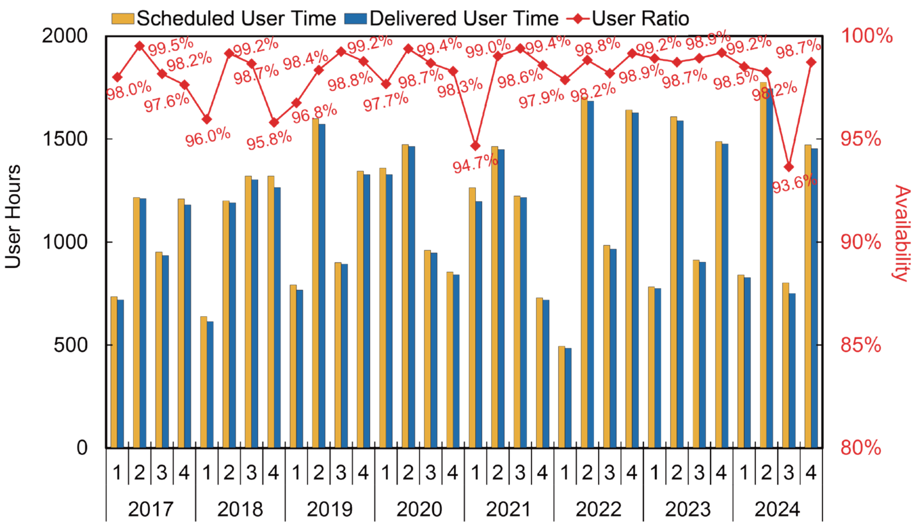

Fig. 4: User time and beam availability of the TPS from 2017 onward.

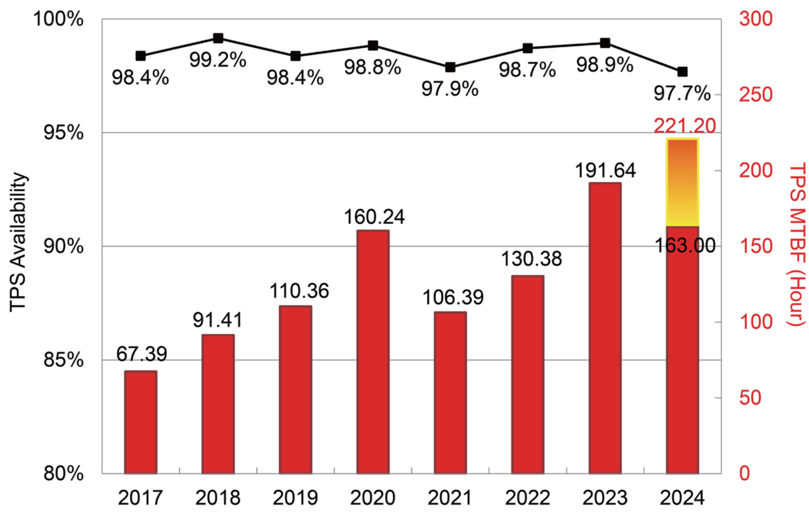

Fig. 5: MTBF and beam trip statistics of the TPS from 2017 onward. In 2024, the MTBF with and without seismic induction statistics was 163 hours and 221.2 hours, respectively.

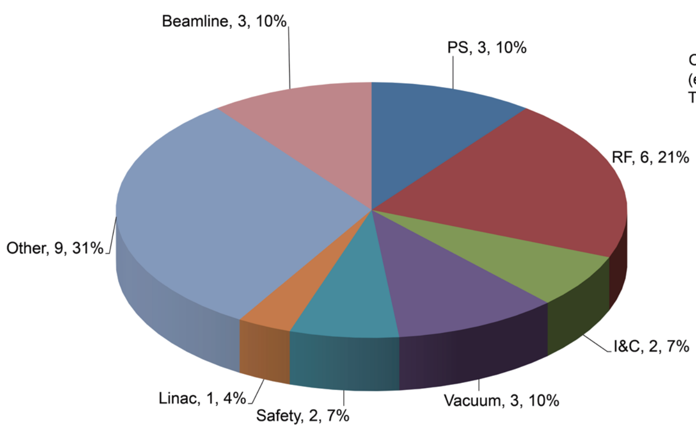

Fig. 6: Proportions of beam trips of the TPS accelerators in 2024. There were 29 trip events in total. “Other” includes 8 earthquake events and 1 TPC voltage drop.

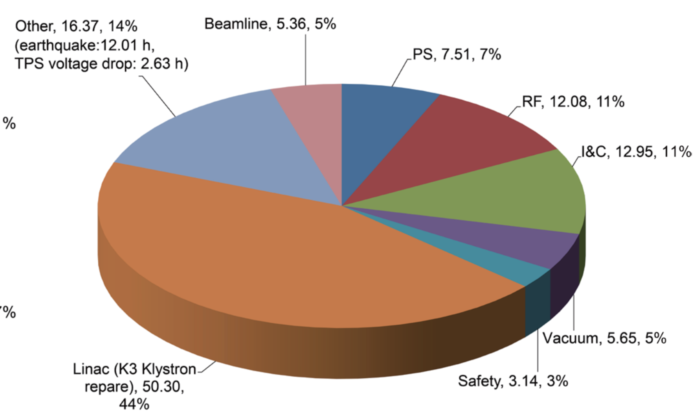

Fig. 7: Proportions of downtime in the TPS accelerators in 2024 (totaling 113.36 hours). The major failure times were as follows: Linac, 50.3 hours; other, 16.37 hours; I&C, 12.95 hours; and RF, 12.08 hours.