Status of TLS and TPS Accelerators

Taiwan Light Source (TLS)

Machine Parameters of the TLS

The Taiwan Light Source (TLS) passed its thirty-year anniversary of first light in 2023. After its inception in 1993, the TLS officially requested experimental proposals and opened to users with three soft X-ray beamlines: HSGM, LSGM and Seya. The original design of the TLS was a triple bend achromatic lattice with 1.3 GeV of beam energy and 200 mA of beam current. After several phases of upgrades, the accelerators have the features of 1.5 GeV with a maximum 360 mA stored beam current, top-up injection, a superconducting radio-frequency (SRF) cavity, a liquid-helium cryogenic system, superconducting wigglers (SCWs) and the most advanced feedback system for orbits and bunch-to-bunch stabilities. Several of these features were pioneering and unique features of the low-energy synchrotron community. The major parameters of the TLS are listed 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 sixfold symmetry storage ring included four room-temperature undulators, a wiggler, and five SCWs, equipping TLS with the most densely packed SCW configuration in the community. SCWs can generate high-energy photons for X-ray users. The parameters 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

At the initial top-up injection, the stored beam current was limited to 200 mA in early 2005 due to restrictions of the beam stabilities and capabilities of the RF system. The TLS gradually increased the stored beam current and reached 360 mA after the installation of the SRF module and upgraded the feedback system in 2010. The performance indicators for TLS operation from 2011 to 2023 are shown in **Fig. 1**. This availability is defined as the ratio of the delivered user time to the scheduled user time, the mean time between failures (MTBF) is defined as the ratio of the scheduled user time to the number of system faults, and the beam stability index is defined as the shot-to-shot photon intensity variation in the diagnostic beamline with a ratio better than 0.1%. The annual availability was 98.99%, with a scheduled user time of 4,791 hours in 2023. The MTBF was 199.6 hours. Beam stability was maintained within 0.1% and 0.2%, with respective rates of 99.29% and 99.87%. One of the major replacements and decisions included changing the pulsed klystron vendor to Canon to improve the operation reliability and stability of the TLS Linac system in 2023.

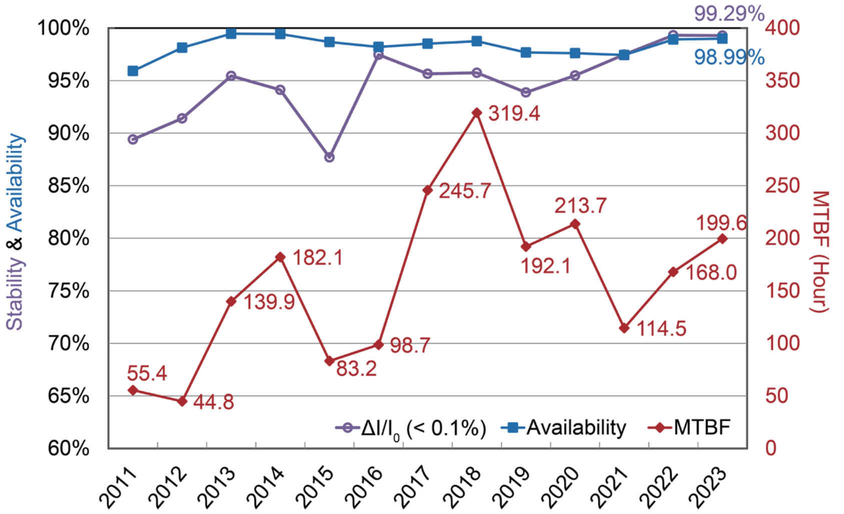

Fig. 1: Annual beam stability index of 0.1%, availability, and MTBF of the TLS.

Downtime and Failure Analysis of the TLS

In 2023, there were 23 beam trips and 48.45 hours of downtime in total. A SRF system needs to provide high power to the stored beam and operate at 4.5 K with a cryogenic system, which is complicated and the most deteriorated system; additionally, this system requires the largest portion of the annual trips and exhibits a fast recovery time. The contributions from each subsystem of the TLS facility are illustrated in **Figs. 2 and 3**. The major downtime contributes to the Linac system as it malfunctions, which cannot accelerate electrons to adequate beam energy for injection into the booster. This process transferred the top-up injection mode to decay mode at the storage ring because a stored current less than 300 mA was defined as downtime. In terms of downtime, the 2nd-ranking factor is the power supply, and some of these power supplies were in service for more than 30 years. Alternative solutions to replace troublesome and aging power supplies are under evaluation.

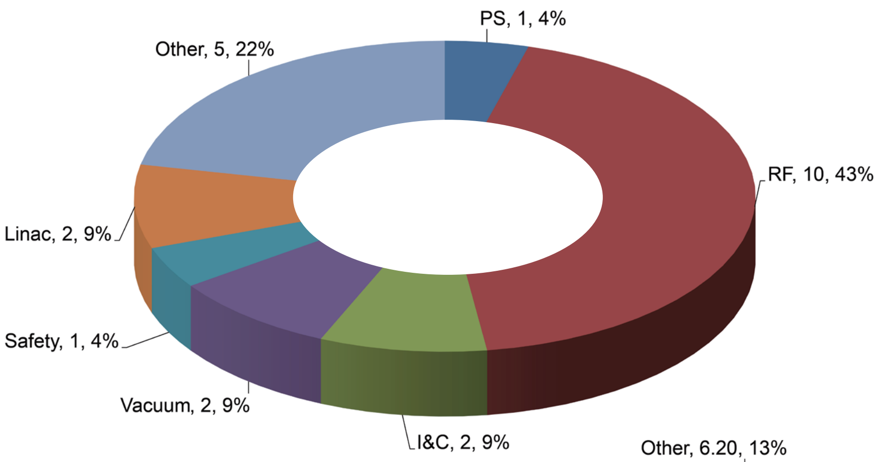

Fig. 2: Rations of beam trips for the TLS accelerators in 2023. RF stands for Radio Frequency; PS stands for Power Supply; and I&C stands for Instrumentation & Control. (23 trip events in total)

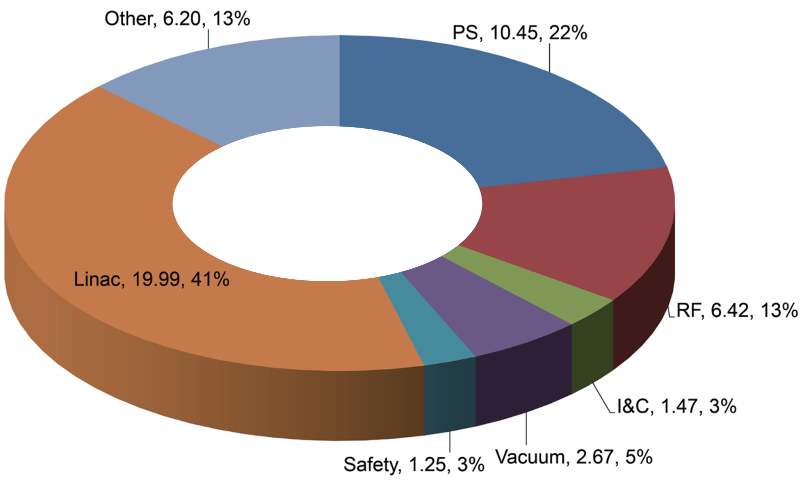

Fig. 3: Downtime distribution for the TLS accelerators in 2023. The major failure times are as follows: LINAC, 19.99 hours; PS, 10.45 hours; RF, 6.42 hours; and other, 6.20 hours. (Accumulated for 48.45 hours in total)

Taiwan Photon Source (TPS)

Machine Parameters of the TPS

The Taiwan Photon Source (TPS) has been in operation for seven years since it officially opened to user proposals in 2016. Within the TPS, the storage ring includes a strong focusing double bend achromatic lattice that features low emittance, top-up injection, SRF module operation, long straight sections and high stability. **Table 3** lists the major parameters of the TPS storage ring for current operation. The TPS accelerators include concentric storage rings and booster rings in the same tunnel due to the limited space on the campus and the consideration of energy savings.

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 became operational for users in the last quarter of 2016 with a beam current of 300 mA, which was raised to 400 mA in December 2017 and was then regularly operated before being increased to 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 has caused delays in the delivery of several key components for both Phase-II and Phase-III beamlines. Despite these challenges, through dedicated collaboration between venders and NSRRC staff, 15 beamlines have been available to users in 2023.

The scheduled and delivered user times and availability are shown in **Fig. 4** on a quarter-to-quarter basis since 2017. In 2023, the annual availability was 98.9%, with a scheduled user time of 4,791 hours. The MTBF reached a record high of 191.64 hours, as shown in the data of **Fig. 5** describing the annual availability.

Downtime and Failure Analysis of the TPS

In 2023, there were 24 beam trips and 50.79 hours of total downtime. The contributions from each subsystem of the TPS facility to this downtime are illustrated in **Figs. 6 and 7**. The subsystem involving most beam trips and downtime is the SRF system, with this fragility attributed to the high current operation and over 0.5 megawatts of power that are applied to the beam within a 4.5 K cryogenic system. In recent years, the TPS and TLS linear accelerator systems have exhibited similar performance characteristics. However, aging phenomena have been observed in TLS Klystrons, resulting in the failure of electron beam injection into the TLS booster ring. Consequently, the operation mode of the storage ring has changed to decay mode. This issue was addressed by changing Klystron suppliers. The TPS linear accelerator system will adopt a similar approach to replace the Klystron supplier. Nonetheless, the overall reliability of these subsystems has gradually improved in recent years to achieve very stable operation and prolong the MTBF. (Reported by Hung-Jen Tsai)

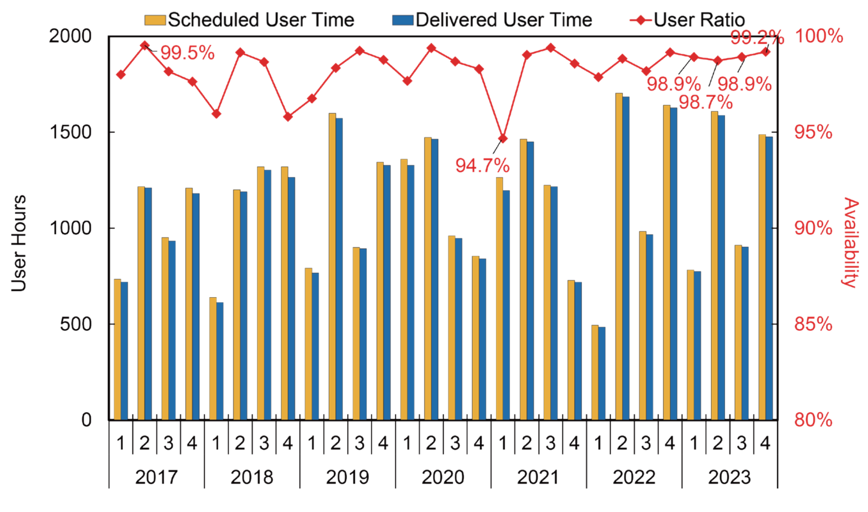

Fig. 4: User time and beam availability of the TPS from 2017 onward.

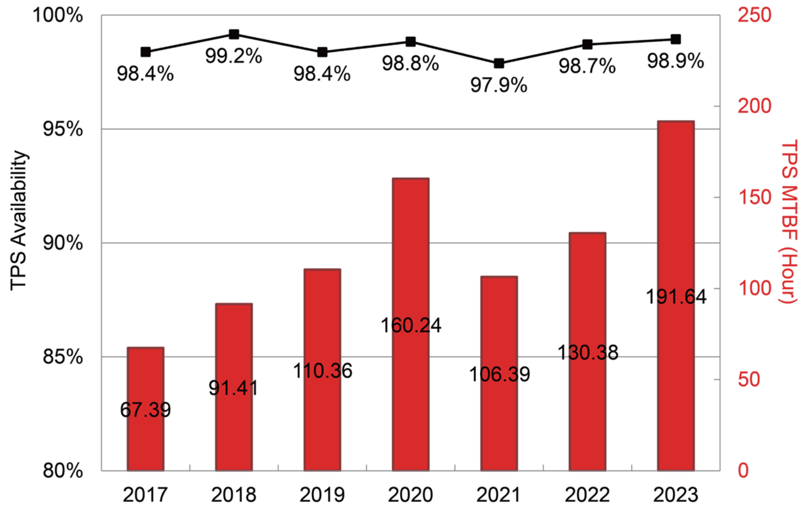

Fig. 5: MTBF and beam trip statistics of the TPS from 2017 onward.

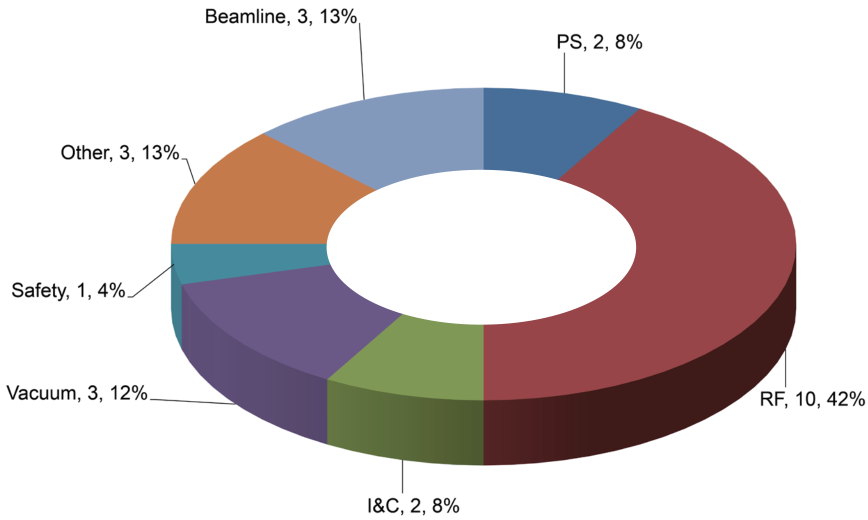

Fig. 6: Rations of beam trips of the TPS accelerators in 2023. (24 trip events in total)

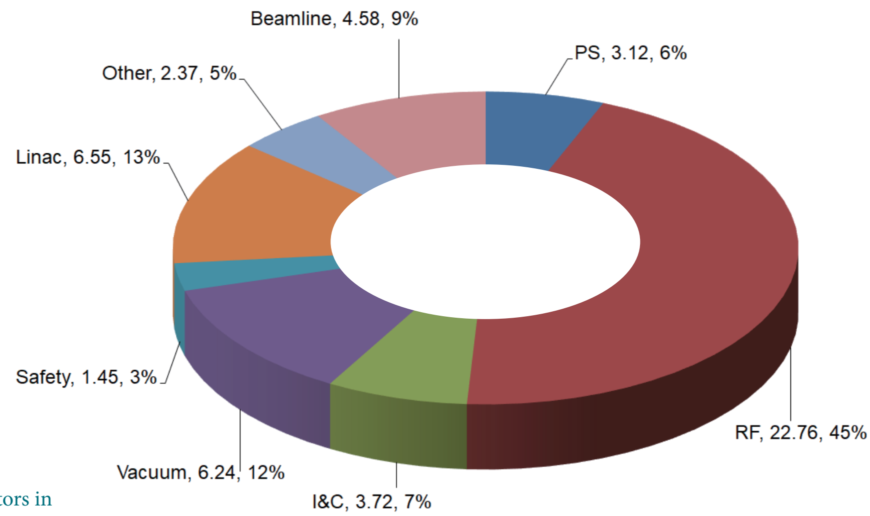

Fig. 7: Proportions of downtime in the TPS accelerators in 2023. (50.79 hours in total)