Status of TLS and TPS Accelerators

Taiwan Light Source (TLS)

Machine Parameters of TLS

As a compact synchrotron light source with nine traditional and superconducting insertion devices in total to serve users for 28 years, the Taiwan Light Source (TLS) accelerator features top-up injection, superconductivity RF module operation, and modern feedback technologies. Listed in **Table 1** are the major parameters of the TLS storage ring for current operation. The locations of the insertion devices and the related parameters are shown in **Fig. 1** and listed in **Table 2**, respectively.

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 (v_x/v_y)	7.303/4.175
RF voltage (MV)	1.6
Lifetime (hour)	7.5

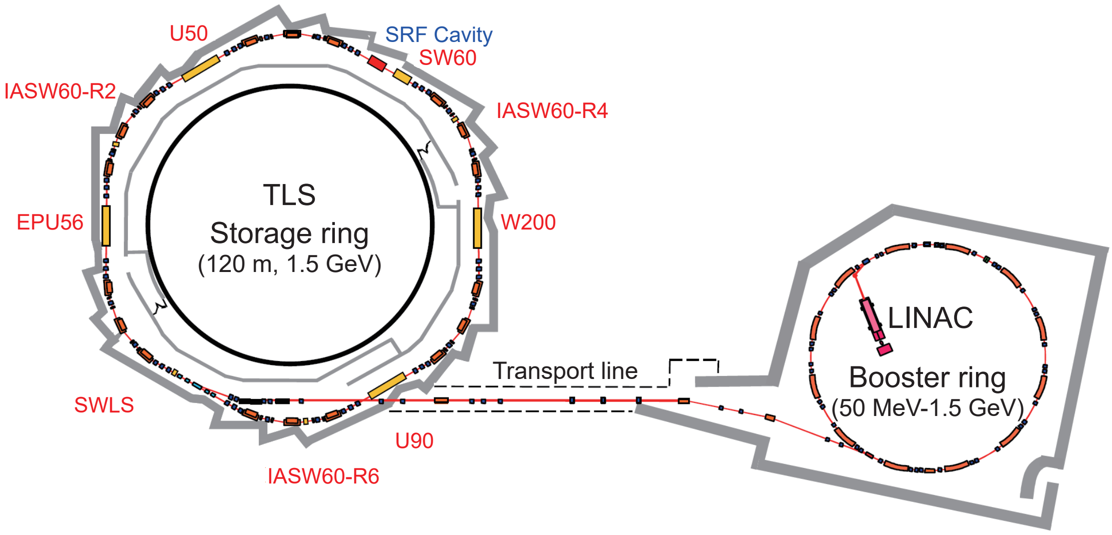

Fig. 1: Layout of the TLS accelerator.

Table 2: Main parameters of insertion devices 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 beginning of 200-mA top-up injection operations in October 2005 immediately after installation of the SRF module, the TLS gradually raised the stored beam current to achieve 360 mA in 2010. Performance indicators for TLS operation from 2011 to 2022 are shown in **Fig. 2**, in which availability is defined as the ratio of delivered user time to the scheduled user time, the mean time between failures (MTBF) as the ratio of scheduled user time to number of faults, and the beam stability index as the shot-to-shot photon intensity variation of the diagnostic beamline with a ratio better than 0.1%. In 2022, the annual availability was 98.9% with a scheduled user time of 5,040 hours, the MTBF was 168 hours, and the beam stability was 99.3%.

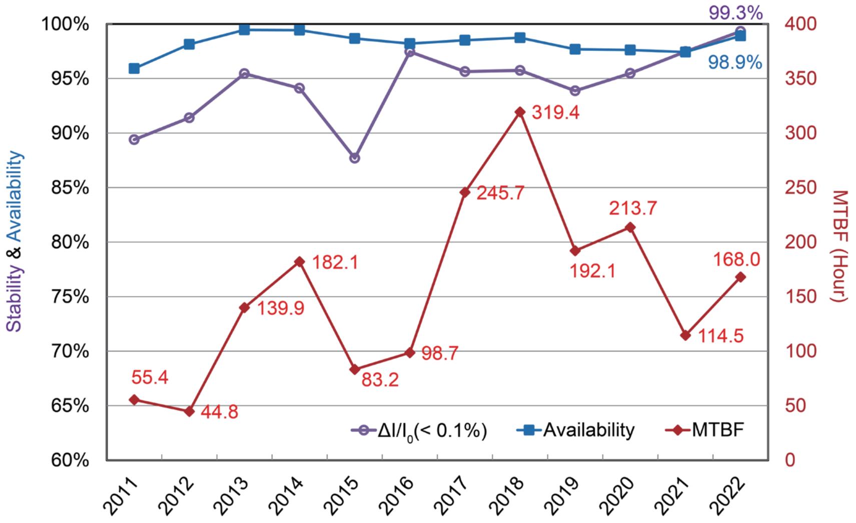

Fig. 2: Annual values for the beam stability index of 0.1%, availability, and MTBF of the TLS from 2011 to 2022.

Downtime and Failure Analysis of the TLS

In 2022, there were a total of 29 beam trips. The accumulated downtime of each subsystem is shown in **Fig. 3**, with a total of 55 hours. The major downtime of 21 hours is contributed by other factors, including earthquakes, power spikes, noise, and beamlines.

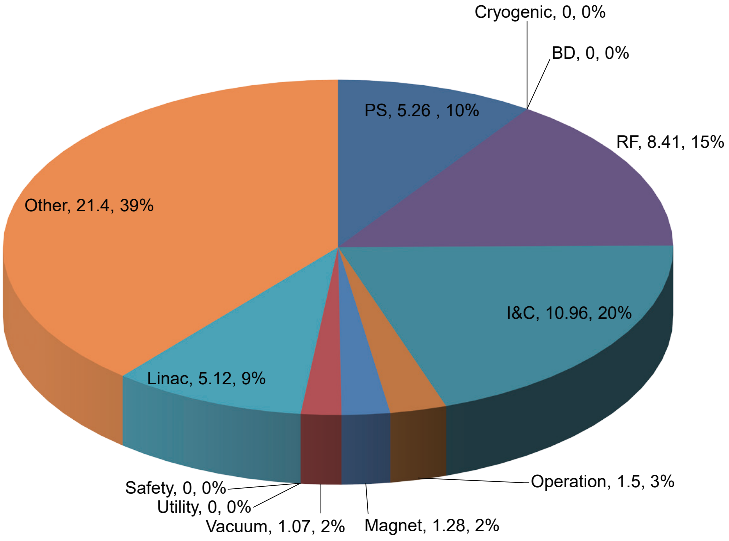

Fig. 3: Downtime distribution for the TLS accelerator in 2022. (Downtime 55 hours)

Taiwan Photon Source (TPS)

Machine Parameters of the TPS

As a synchrotron light source opened to users for less than seven years, the Taiwan Photon Source (TPS) accelerator features low emittance, top-up injection, superconductivity RF module operation, and high stability. Listed in **Table 3** are the major parameters of the TPS storage ring for current operation. The TPS accelerator tunnel includes a storage ring and a booster ring placed concentrically.

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
RF voltage (MV)	2.8
Synchrotron tune (ν_s)	5.42 × 10^{-3}

Statistics of TPS Machine Operation

The TPS was first opened to users in the last quarter of 2016 with a beam current of 300 mA, which was raised to 400 mA in December 2017, and then regularly reached 450 mA on the last day of 2020. In 2021, beam operation reached 500 mA for users. Both the scheduled and delivered user times and the availability since 2016 are shown in **Fig. 4** (see next page) quarter by quarter. In 2022, the annual availability was 98.7% with a scheduled user time of 4,824 hours and the mean time between failures reached 130 hours, as shown in **Fig. 5** (see next page) together with the year statistics since 2017.

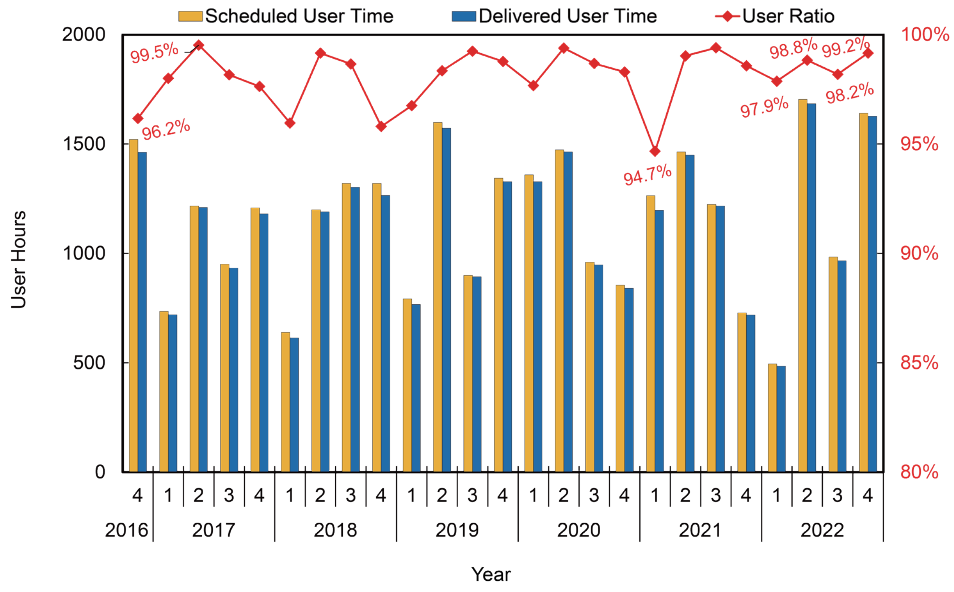

Fig. 4: User time and beam availability of the TPS from 2016 onward.

Downtime and failure analysis of the TPS

In 2022, there were 36 beam trips and 62 hours of downtime in total. The contributions from each subsystem are illustrated in **Fig. 6** and **Fig. 7**. The subsystems have all been gradually improved in past years to achieve stable operation. (Reported by Chang-Hor Kuo)

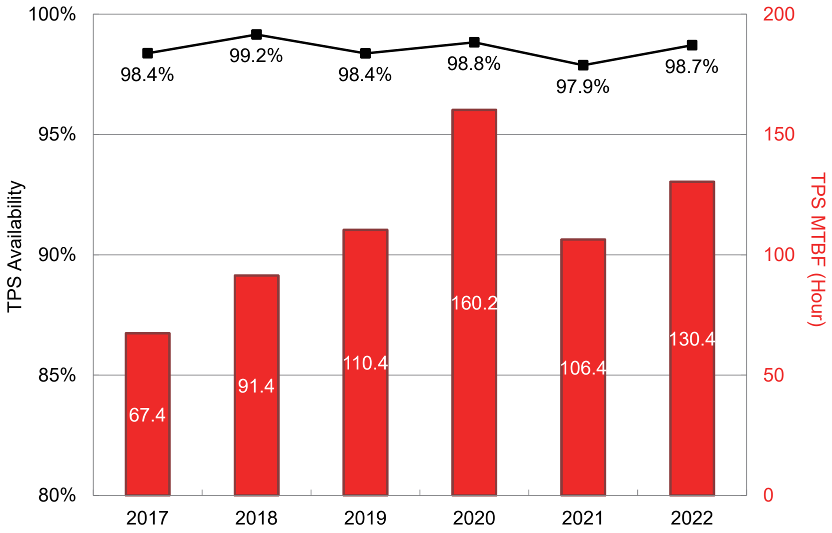

Fig. 5: MTBF and beam trip statistics of the TPS from 2017 onward.

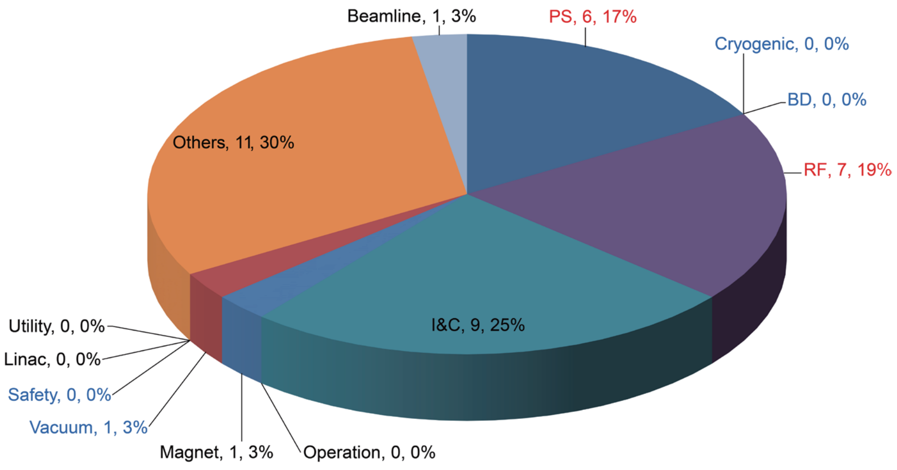

Fig. 6: Proportions of beam trips of the TPS accelerator in 2022. (36 trip events in total)

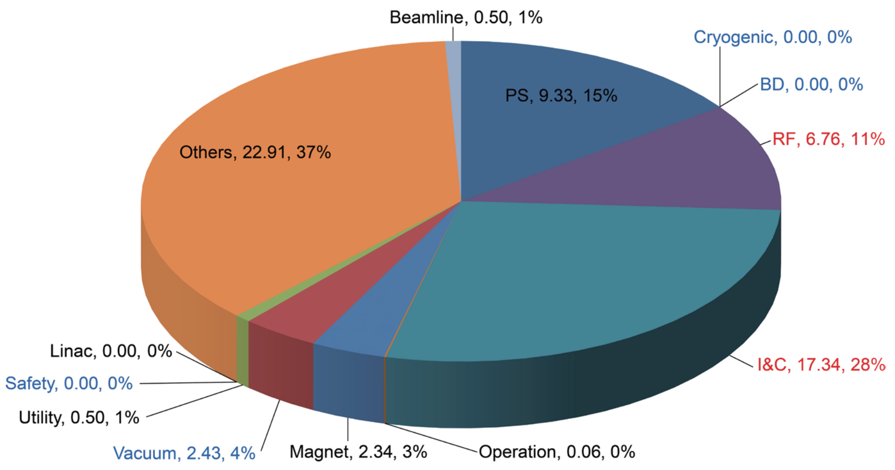

Fig. 7: Proportions of downtimes of the TPS accelerator in 2022. (62.17 hours in total)

Phase Drift Compensation Loop for a Radiation Frequency System of TPS Booster Ring

In synchrotron radiation light sources, the energies of electrons are provided by a radiation frequency (RF) system, which consumes substantial power. In 2015, members of the RF group worked to reduce this power consumption and develop an economic operation for RF systems in the Taiwan Light Source (TLS) booster ring.[1,2] In 2018, this economic operation system was implemented in the Taiwan Photon Source (TPS) booster ring.[3] The standard operation condition of the TPS is currently top-up mode operation with a 500-mA beam current of multiple bunches but with a single bunch of 3 mA in the middle of clear bunches (also known as hybrid-mode operation). Because of the high injection efficiency and long lifetime (over 8 h) during normal user operation, the injection period accounts for a small portion of the total time required to maintain a beam current fluctuation of less than 5 mA. Thus, the energy-saving operation is expected to reduce the power consumption of the booster ring considerably. Briefly, electron beams are injected from the booster ring to the storage ring to replenish the lost beam every 242 s. Thus, the booster ring operates only during the 2-s injection period and then rests for the remaining 240 s. At the beginning of the energy-saving operation for the TPS booster ring, only the magnets of the booster ring are powered off during the 240-s resting time. However, because the TPS booster RF system consumes 60 kW of electricity, the system should be operated in the power-saving mode.

Problem of Digital Low-Level RF During Economic Operation

Economic operation is realized using an energy-saving module, which controls the anode voltage and cathode current of the klystron to operate at a high level in the injection mode and at a low level in the standby mode. During switching between these two modes, the instant phase jump caused by the change in the klystron cathode current is beyond the compensation capacity of the digital low-level RF (DLLRF) system. Compared with an analog low-level RF system at the TLS or the TPS, the DLLRF control system has a wider bandwidth and a faster feedback response for improved feedback performance. Thus, the DLLRF control system can sense the aforementioned instant phase jump and consequently drive the proportional-integral-derivative (PID) controller to reach saturation rapidly and thereby trigger RF interlocking to protect the system. **Figure 1** (see next page) depicts the phase jump as a digital-to-analog converter (DAC) output phase. To maintain a constant gap voltage phase, which is depicted as an analog-to-digital converter (ADC) phase in **Fig. 1**, the DLLRF system must compensate for phase differences up to approximately ±85°, similar to the DAC phase behavior during mode switching. As displayed in **Fig. 2** (see next page), this phenomenon enables the RF trip to occur smoothly. In **Fig. 2**, t_1 is the preparation zone for the klystron to increase the cathode current (I_{cc}) for pulling the maximum power up by increasing the anode voltage, so as anode current (I-anode) raising, whereas t_2 represents the first ramp of the gap voltage, which fails in this case. This failure clearly occurs as a result of the oscillation of