Status of Taiwan Light Source and Taiwan Photon Source Accelerators

Taiwan Light Source (TLS)

Machine Parameters of the TLS

The TLS accelerator is a compact synchrotron light source with nine conventional and superconducting insertion devices, and it has served users for 27 years. The TLS accelerator features top-up injection, superconductivity radio frequency (RF) module operation, and modern feedback technology. **Table 1** lists the major parameters of the TLS storage ring for current operations, **Fig. 1** illustrates the locations of the insertion devices, and **Table 2** lists the related parameters.

Table 1: Main parameters of 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
RF voltage (MV)	1.6
Lifetime (hour)	7.5

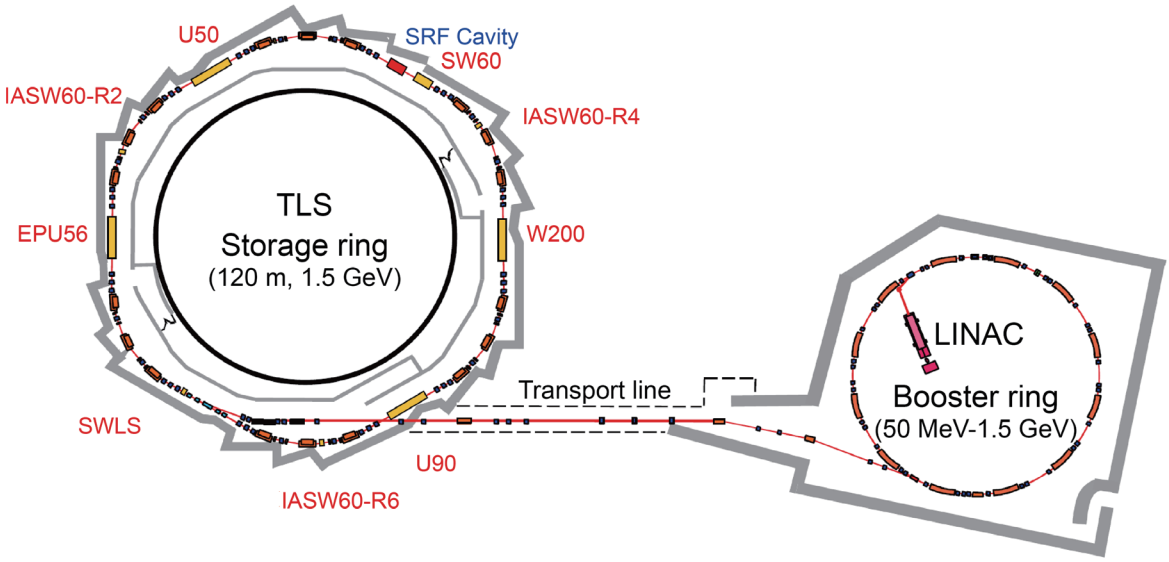

Fig. 1: Layout of the TLS accelerator.

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

After 200-mA top-up injection operations started in October 2005 following the installation of a superconducting radio frequency module, the TLS gradually increased the stored beam current, which reached 360 mA in 2010. The performance indicators for TLS operations from 2011 to 2021 are presented in **Fig. 2**, in which availability is defined as the ratio of

delivered user time to scheduled user time, mean time between failures (MTBF) is the ratio of scheduled user time to number of faults, and beam stability index is the shot-to-shot photon intensity variation of the diagnostic beamline with a ratio less than 0.1%. In summary, by 2021, availability was 97.4% with a scheduled user time of 5,040 hours, MTBF was 115 hours, and time of beam stability was 97.5%.

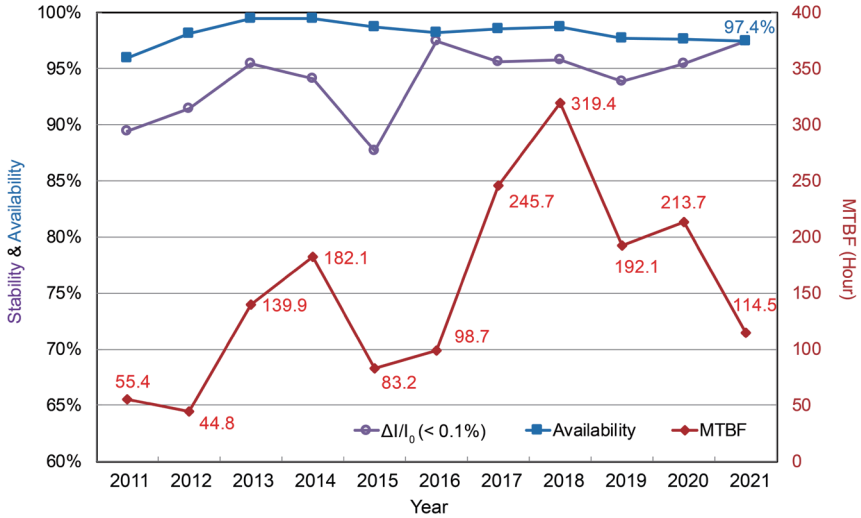

Fig. 2: Beam stability index (0.1%), availability, and MTBF of the TLS from 2011 to 2021.

Downtime and Failure Analysis of the TLS

In 2021, a total of 43 beam trips were recorded. The accumulated downtime of each subsystem is presented in **Fig. 3**, and the total accumulated downtime was 129 hours. Among the various contributors to downtime (including earthquakes, power spikes, noises, and beamlines), the RF system accounted for the largest proportion at 47.3 hours.

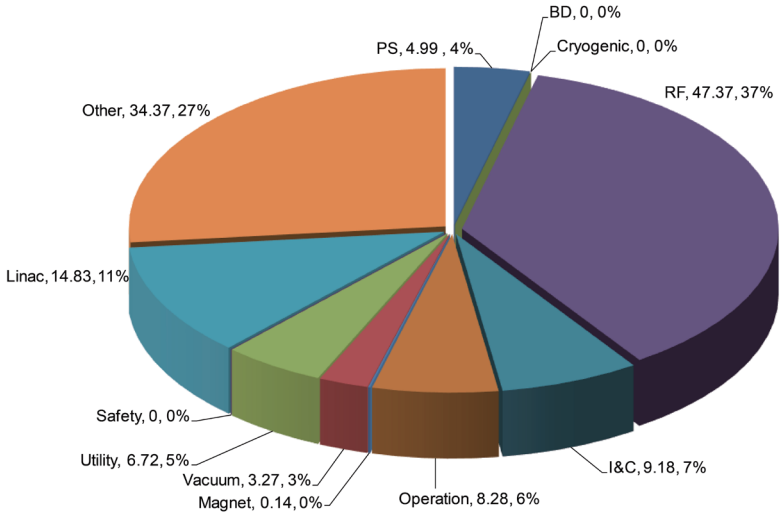

Fig. 3: Downtime contribution of the TLS accelerator in 2021. (Downtime 129 hours)

Taiwan Photon Source (TPS)

Machine Parameters of the TPS

As a synchrotron light source that has only been made available to users for less than 6 years, the TPS accelerator features low emittance, top-up injection, superconductivity RF module operation, and high stability. **Table 3** lists the major parameters of the TPS storage ring for current operations. The TPS accelerator tunnel comprises a storage ring and a booster ring that are arranged concentrically.

Table 3: Main parameters of TPS storage ring.

Beam energy (GeV)	3
Circumference (m)	518.4
Current/design (mA)	400/500
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 made available to users in the fourth quarter of 2016 with a beam current of 300 mA, which was increased to 400 mA in December 2017 and subsequently reached 450 mA in the later period of 2020. In 2021, the beam current reached 500 mA for users. The scheduled user time, delivered user time, and availability of TPS from 2019 onward are presented on a quarter-by-quarter basis in **Fig. 4** (see next page). In 2021, annual availability was 97.9%, scheduled user time was 4,681 hours, and MTBF was 106 hours (**Fig. 5**, see next page).

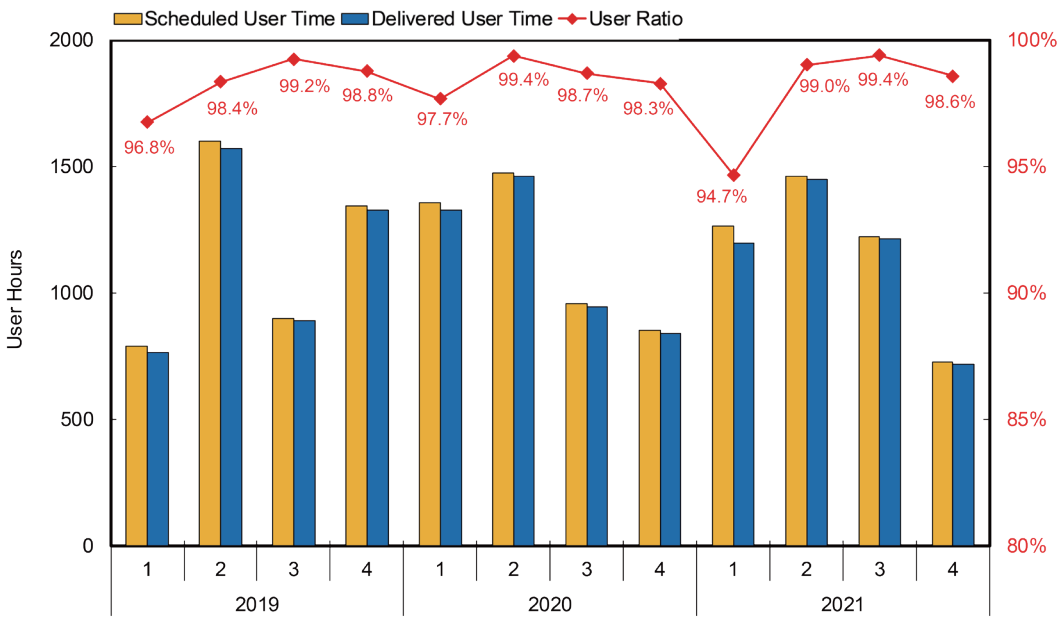

Fig. 4: User time and beam availability of Taiwan Photon Source from 2019 onward.

Downtime and Failure Analysis of the TPS

In 2021, a total of 43 beam trips and 99 hours of downtime were recorded. The contributions of each subsystem with respect to beam trips and downtime are illustrated in **Figs. 6 and 7**, respectively. The subsystems all gradually improved over the years to attain stable operations.

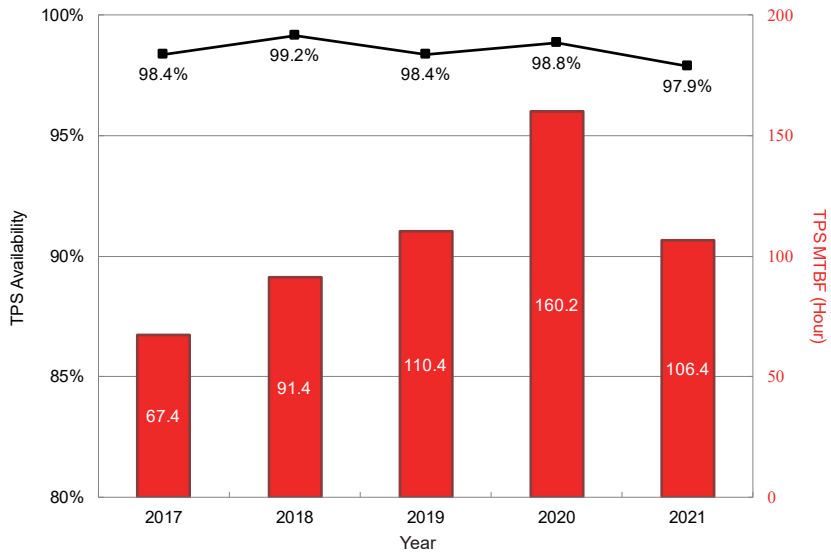

Fig. 5: Mean time between failures and beam trip statistics of TPS from 2017 onward.

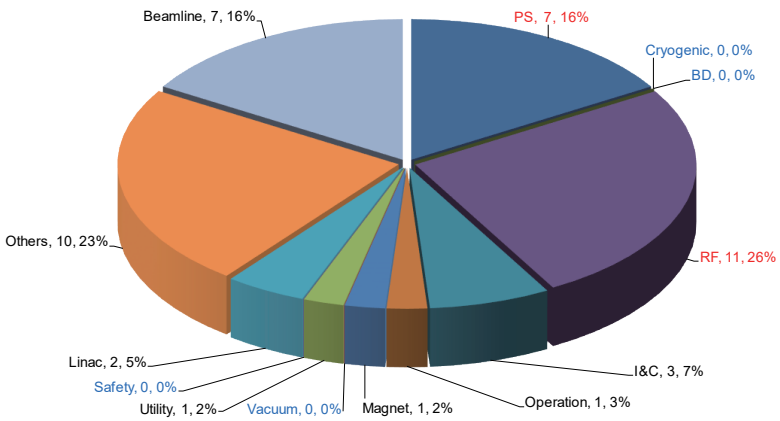

Fig. 6: Beam-trip distribution of TPS accelerator in 2021. (43 trip events in total)

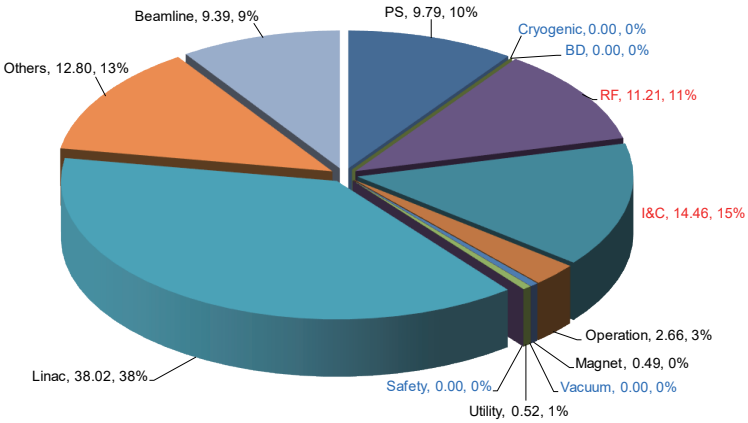

Fig. 7: Downtime distribution of TPS accelerator in 2021. (99.3 hours in total)

High-Beam Current Operation with a Digital Low-Level Radio Frequency System

The purpose of a low-level radio frequency (LLRF) system is to manipulate the amplitude and the associated phase of the accelerating field provided by the RF cavity. A digital LLRF (DLLRF) control system based on the field programmable gate arrays (FPGA) platform provides higher field stability, more precise field control, and more effective noise reduction for the accelerating field. The analog LLRF system of the Taiwan Photon Source (TPS) booster ring was replaced by the DLLRF system at the beginning of 2018.[1] The difference between setting points and measured values during the ramping process was controlled within 0.3% and 0.2° for the accelerating field amplitude and phase, respectively. Moreover, the sidebands of 60-Hz noise and their high-order harmonics were suppressed to lower than

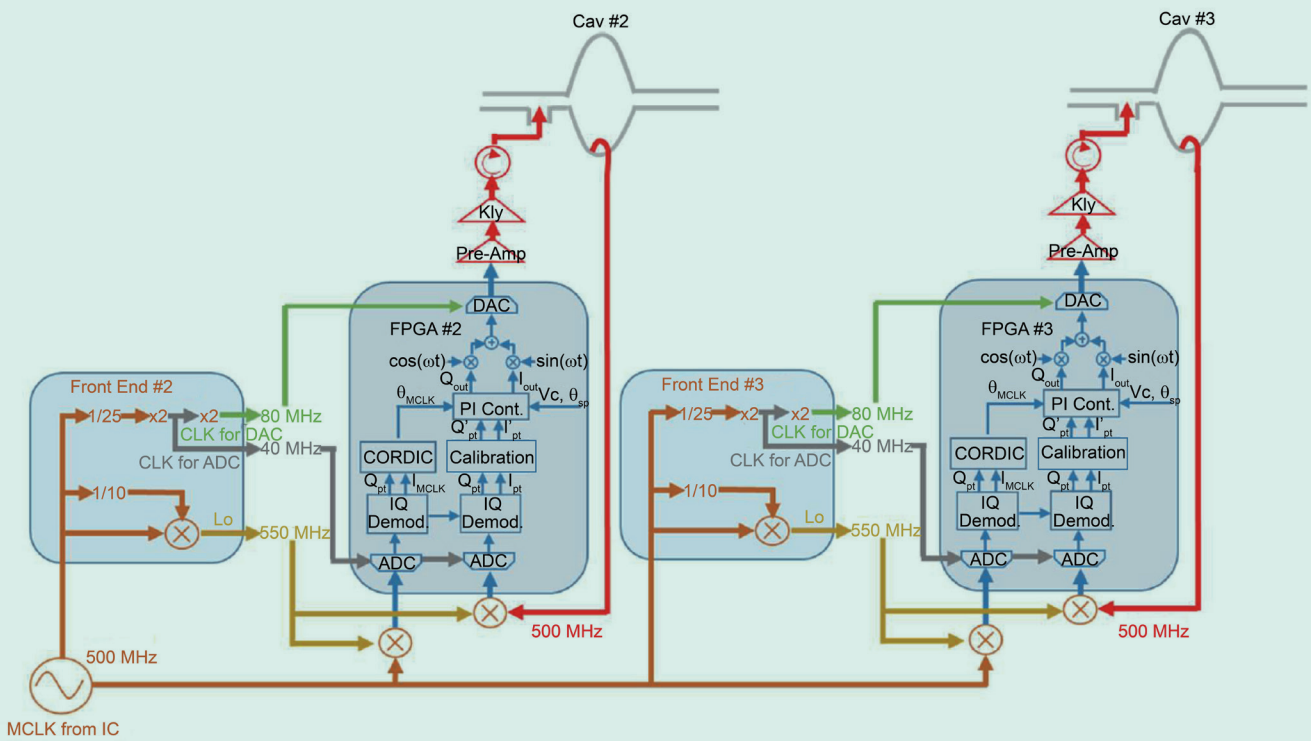

Fig. 1: Schema of the DLLRF system for the TPS storage ring.