Status of TLS and TPS Accelerators

Taiwan Light Source (TLS)

Machine Parameters of TLS

As a compact synchrotron light source but with nine traditional and superconducting insertion devices in total that have served users for 26 years, 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, whereas locations of insertion devises and related parameters are shown in **Fig. 1** and listed in **Table 2**, respectively.

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

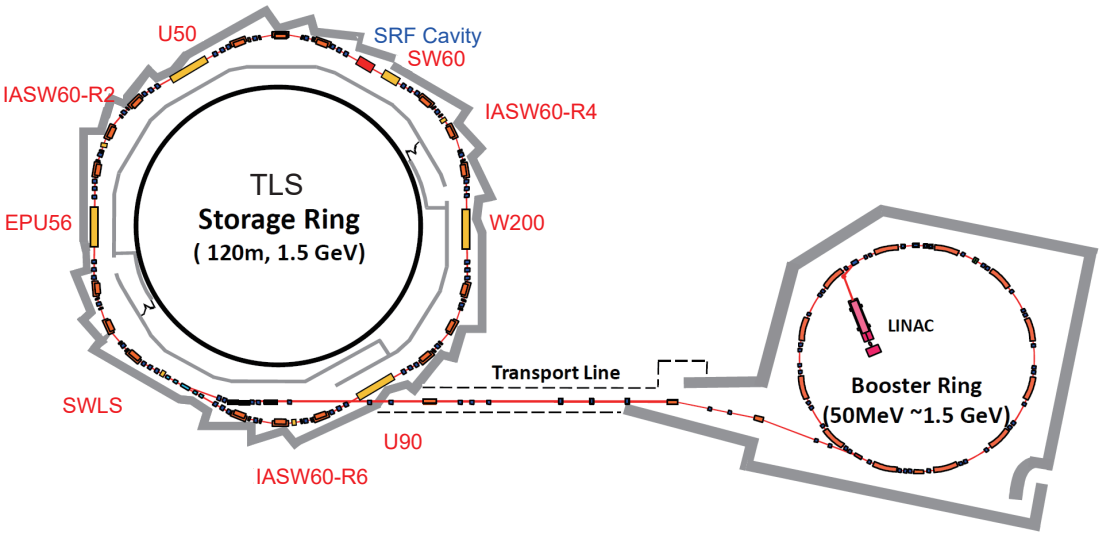

Fig. 1: Layout of the TLS accelerator.

Table 2: Main parameters of insertion devices in 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 directly after installation of the SRF module, TLS gradually raised the stored beam current to achieve 360 mA in 2010. Performance indicators for TLS operation from 2011 to 2020 are shown in **Fig. 2**, in which availability is defined as the ratio of delivered user time to the scheduled user time,

Mean Time Between Failure (MTBF) as the ratio of scheduled user time to number of faults, and beam-stability index as the photon-intensity variation shot to shot of the diagnostic beamline with a ratio better than 0.1%. In summary of 2020, the availability was 93.3% with a scheduled user time 5,112 hours; MTBF was 232.4 hours, and beam stability was 95.5% with 0.1% tolerance. In November, the klystron of the LINAC failed; the only spare klystron was sent back to its manufacturer THALES in France for high-power test due to an impact loading during air delivery. It took ten days to try to recover the failed klystron; the availability thus decreased from 97.6% to 93.3%. In December it took another three days to replace it with the delivered new klystron.

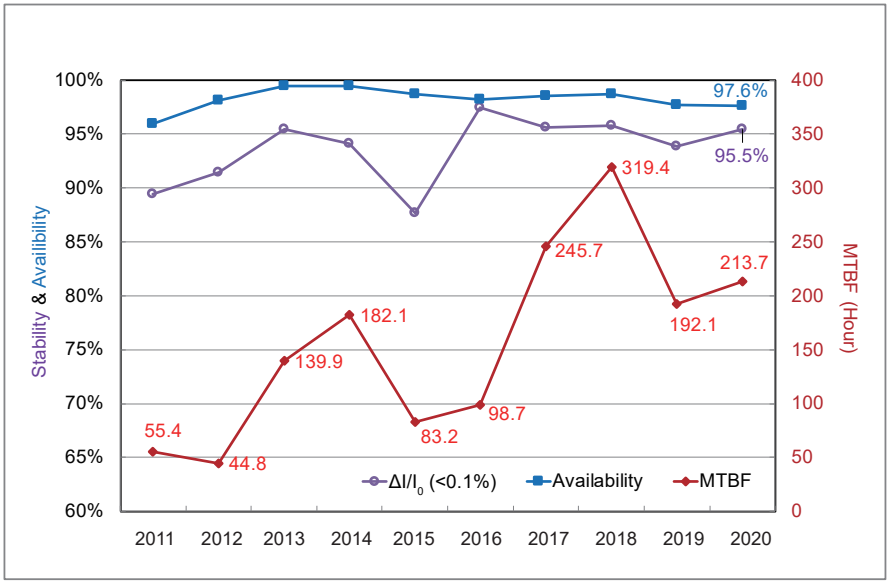

Fig. 2: Summary of beam-stability index 0.1%, availability and MTBF of TLS from 2011 to 2020.

Downtime and Failure Analysis of TLS

In 2020, in total there were 22 beam trips. The accumulated downtime of each subsystem is shown in **Fig. 3**, with 344.3 hours in total. The major downtime, 303.7 hours, was contributed from the LINAC system, in which the klystron event took 301 hours. The others including earthquake, power spike, noise, beamline, injection kicker, RF system *etc*. became minor in 2020.

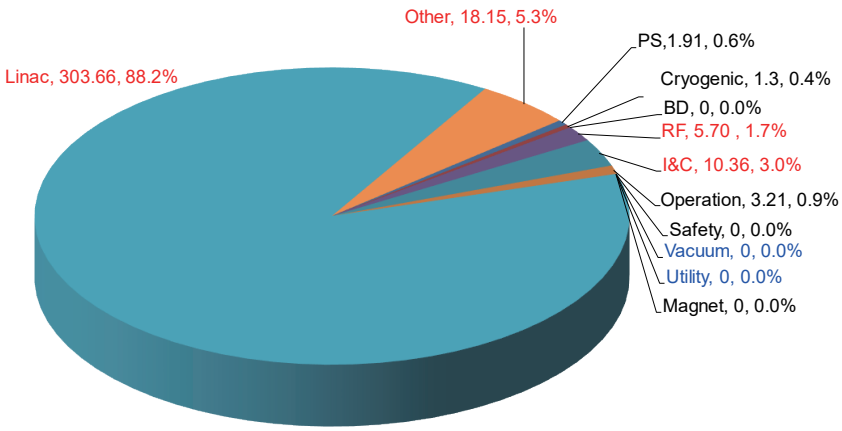

Fig. 3: Downtime contribution of TLS accelerator in 2020. (Downtime 344.3 hours)

Taiwan Photon Source (TPS)

Machine Parameters of TPS

As a synchrotron light source opened to users less than five years ago, TPS accelerator features low emittance, top-up injection, superconductive 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 concentrically.

Table 3: Main parameters of TPS storage ring.

Beam energy (GeV)	3
Circumference (m)	518.4
Current/design (mA)	450/500
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

TPS was first opened to users in the last quarter of 2016 with beam current 300 mA, raised to 400 mA in December 2017, and then regularly reached 450 mA in the latter days of 2020. Both scheduled and delivered user time and the availability since 2018 are shown in **Fig. 4**, quarter by quarter. In 2020, the annual availability was 98.5% with scheduled user time 4,647 hours; MTBF attained 160.2 hours as shown in **Fig. 5** together with the year statistics since 2017.

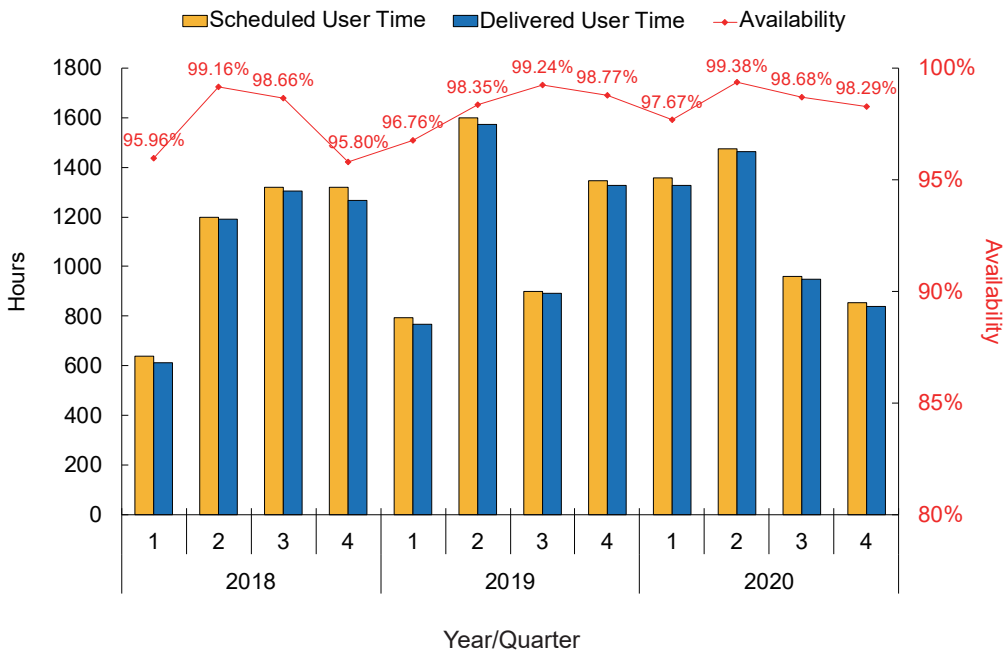

Fig. 4: User time and beam availability of TPS since 2018.

Downtime and Failure Analysis of TPS

In 2020, there were 28 beam trips and downtime 68 hours in total. The contributions from each subsystem are illustrated in **Figs. 6 and 7**, respectively. The sub-systems are all gradually improved in past years to achieve stable operation.

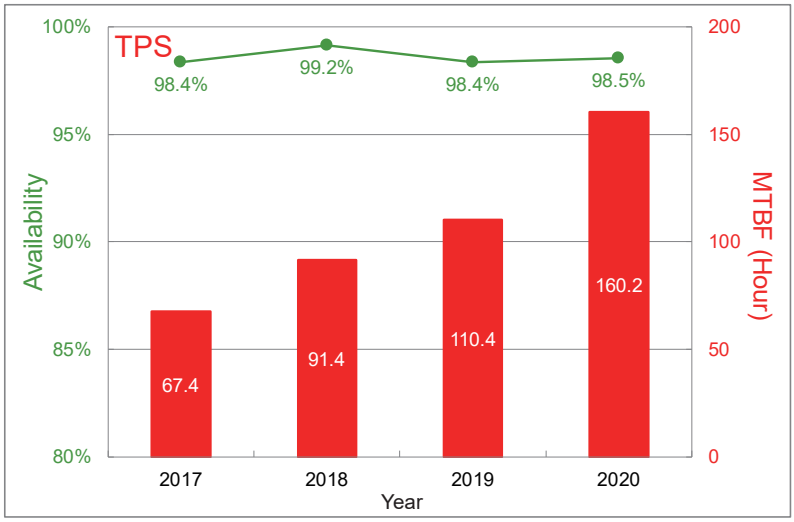

Fig. 5: MTBF and beam-trip statistics of TPS since 2017.

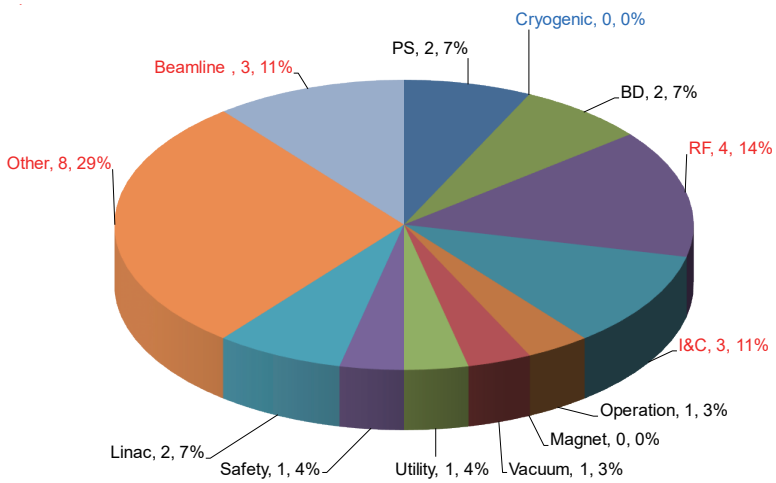

Fig. 6: Beam-trip distribution of TPS accelerator in 2020. (28 trip events)

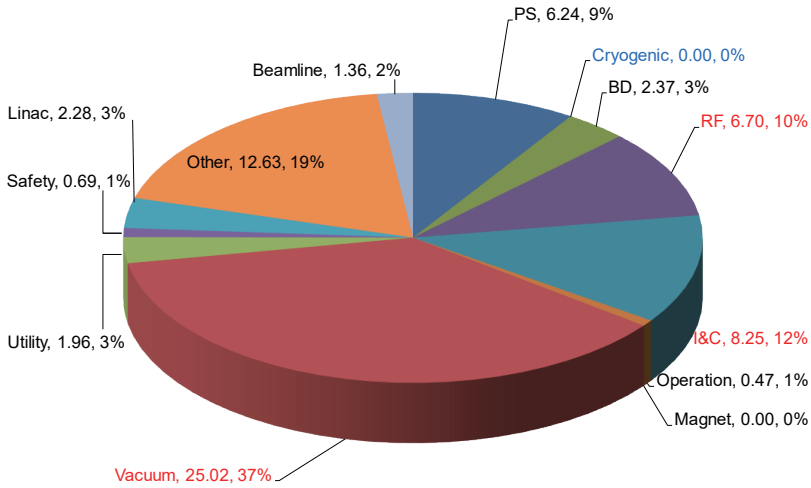

Fig. 7: Downtime distribution of TPS accelerator in 2020. (Downtime 68 hours)

Progress on Elliptically Polarized Undulators at the NSRRC

Introduction

Because demand for circularly polarized radiation is strong, insertion devices (ID) have been used to provide elliptical fields since the late 1980s. The trend is to increase both the degree of circular polarization and the brightness of the radiation. Among many ID designs, an elliptically polarized undulator (EPU) provides the greatest merit flux and has thus become the workhorse in several facilities. NSRRC has also been developing its own EPU since the 1990s. EPU56 (length 3.9 m) with period length 56 mm was the longest EPU in the world at the time, as seen in **Fig. 1(a)**. It was installed at Taiwan Light Source (TLS, 1.5-GeV storage ring) in service to date. At Taiwan Photon Source (TPS, 3-GeV storage ring), the EPU continues to play an important role in fulfil the needs of EUV of the soft X-ray user community. Up to phase II, in total five EPUs have been installed, as seen in **Table 1**. It is worth noting that, for full utilization of the TPS straight section, the EPU installed this year has length 4.36 m; a new device, flat wire, is installed, which is expected to correct the dynamic multipoles induced by the EPU.

Table 1: History of EPU development at NSRRC.

Year	Name	Facility	Contents	Remarks
1999	EPU56	TLS	$\lambda_u^a = 56$ mm, $G_{min}^b = 20$ mm, $L^c = 3.9$ m	longest EPU in the world, at that time
2015	EPU46	TPS (phase I)	$\lambda_u = 46$ mm, $G_{min} = 14$ mm, $L = 3.8$ m	refurbished by NSRRC
2015	EPU48A		$\lambda_u = 48$ mm, $G_{min} = 13$ mm, $L = 3.4$ m	double EPUs for a long straight section
2015	EPU48B			
2020	EPU66	TPS (phase II)	$\lambda_u = 66$ mm, $G_{min} = 16$ mm, $L = 4.36$ m	flat wire installed within a gap
2020	EPU168		$\lambda_u = 168$ mm, $G_{min} = 27.2$ mm, $L = 4.36$ m	for EUV beamline, flat wire installed

Notes: [a] period length; [b] minimum gap; [c] physical length of EPU.

Description of the Mechanical Structure

The EPU is composed of four Halbach arrays that regulate the amplitude and phase of the vertical and horizontal magnetic fields by the relative motion of the magnet arrays. On driving the diagonal arrays, the EPU can provide various polarizations, such as horizontal linear, circular and vertical linear (VL) polarization. As with general ID operation, the EPU varies the magnetic fields to fulfil the spectral tuning by opening and closing a gap of magnet arrays. In terms of the mechanical structure, the EPU has two driving systems to move magnet arrays: vertical movement to tune photon energy, longitudinal movement to control polarization. The vertical movement is achieved on fixing the magnet arrays on the backing beam, which opens