# Accelerator Design and Construction Progress of TPS Project

Taiwan Light Source (TLS), a 120-m storage ring originally designed for 1.3 GeV, was commissioned and opened to users in 1993. The energy of TLS was subsequently upgraded to 1.5 GeV in 1996. To meet the increasing demand from the X-ray user community, superconducting wigglers were installed in all possible locations of the TLS storage ring, but the demand for further X-ray beamlines with increased brightness is relentless. For the future development of NSRRC, a 3-GeV synchrotron accelerator facility called the Taiwan Photon Source (TPS) was proposed in 2005. The TPS project was officially approved by the government in 2007. The Board of Trustees decided that TPS will be built at the existing NSRRC site. The ground breaking of civil construction began on 2010 February 7. The TPS project is expected to be completed and open to users by the end of 2014. We report here an overview of the accelerator design and the construction progress of TPS project.

**Fig. 1:** A 3D simulation of the NSRRC site with the TPS facility. A new building of torus shape will host the linac, booster, storage ring, beamlines and experimental area of the TPS facility. A new guest house in the activity center is built to accommodate more users.

## Overview of Accelerator Design

The brightness of the photon beam emitted from a storage ring is directly proportional to the current in the stored electron beam and inversely proportional to the size of the transverse electron beam in both directions. To increase the brightness of the photon beam, we must increase the current of the stored beam and decrease the sizes of the transverse beam in a storage ring. For the latter purpose, a storage ring with smaller beam emittance (the area occupied by the electron beam in phase space) is required. Beyond that smaller emittance, the coupling between the horizontal and vertical motions of the beam should be diminished. The beam emittance of an electron storage ring is proportional to the square of the beam energy and to the cube of the bending angle. As we seek to produce brighter X-ray radiation from undulators, the energy of the beam in the TPS storage ring cannot be less than that of TLS. The designed energy of the TPS storage ring is 3 GeV. Once the beam energy is decided, the only way to attain a designed smaller beam emittance is to decrease the bending angle of the dipole magnets. A smaller bending angle implies more numerous dipole magnets in the storage ring, which implies in turn that the largest practicable circumference should be pursued for the TPS storage ring so as to attain a minimal beam emittance while satisfying the requirements of users. Accordingly, the circumference of the TPS storage ring was optimized at 518.4 m while taking into account the geographic constraints imposed by existing buildings and the terrain at the NSRRC site. A 3D simulation of the NSRRC site with the TPS facility appears in Fig. 1. As shown there, a building of torus shape will be constructed to host the linear accelerator (linac), booster synchrotron, storage ring, beamlines and experimental area. The outer circumference of that TPS building is 659.7 m. The existing building for administration and research will be surrounded by the new TPS building. To accommodate the increasing user community, a new guest house in the activity center is located across from the TPS building. A bridge crossing the roof of the TPS building is designed to provide access between offices inside the TPS building and other buildings at the NSRRC site. The detailed civil engineering plan has been reported.[1]

After taking into account the geographic constraints imposed by existing buildings and various technical issues, we chose a concentric design for the booster synchrotron. The booster will be placed in the same tunnel as the storage ring. The circumference of the booster is 496.8 m, perhaps the largest booster synchrotron among light sources of medium energy in the world. A 150-MeV linac will serve to inject the electron beam into the booster. Figure 2 shows a schematic layout of the TPS accelerator complex. The TPS storage ring has six superperiods, each of which consists of four double-bend achromat (DBA) cells. The storage ring has six 12-m straight sections and eighteen 7-m straight sections. One 12-m straight section is reserved for the beam injection. The superconducting RF (SRF) cavities developed for the KEK B-factory is adapted to operate at 500 MHz for the TPS storage ring. Table 1 summarizes major parameters of the baseline design of the TPS storage ring. Technical overviews of the baseline design are available elsewhere.[2, 3]

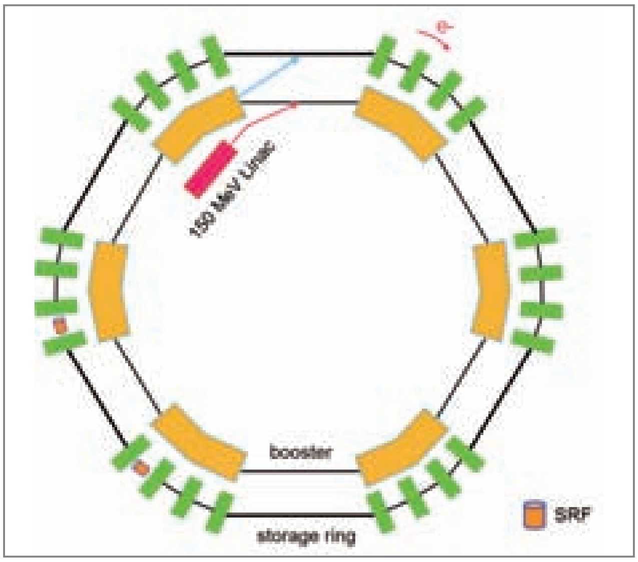


**Fig. 2:** Schematic layout of the TPS accelerator complex. The booster synchrotron is placed in the same tunnel as the storage ring. A 150-MeV linac serves to inject electron beams into the booster. Two 7-m short straight sections will be used for the installation of SRF modules.

The maximum number of beam bunches that can be stored in the storage ring is 864 (the harmonic number of the storage ring). The spacing between adjacent bunches is 2 ns (the inverse of the RF frequency, 500 MHz). To attain a stable orbit at a submicrometre level, a scheme for orbit correction and various systems for beam feedback are implemented. Stringent tolerances are imposed on the manufacture, assembly and installation of all accelerator components and sub-systems.

**Table 1:** Major parameters of the baseline design for the TPS storage ring, assuming 1 % emittance coupling.

| | |
|---|---|
| Natural emittance / nm rad | 1.6 |
| Straight section | 12 m x 6 + 7 m x 18 |
| Beam current / mA | 500 |
| Beam size at 12-m center (H/V) / μm | 165.1 / 9.8 |
| Beam size at 7-m center (H/V) / μm | 120.8 / 5.1 |
| Bunch length (RF @3.5 MV) / mm | 2.86 |
| Energy loss/turn, dipole / keV | 853 |
| Critical photon energy from dipole / keV | 7.12 |
| Maximum number of beam bunches | 864 |

To take advantage of a straight section of length 12 m, two identical undulators will be installed collinearly in the same section. With an appropriate phase delay, the constructive interference between radiation emitted from both undulators could result in a quadrupled brightness. An alternative accelerator design called double mini-$\beta y$ lattice has been obtained that can provide two minima of the beam size in the vertical direction of three 12-m straight sections symmetrically. Figure 3 shows a conceptual illustration of the beam amplitude functions for a double mini-$\beta y$ lattice in the 12-m straight section. The size of the electron beam is proportional to the square root of the amplitude function (the envelope of transverse beam oscillation). The baseline design has only one minimum in the middle of a straight section. The double mini-$\beta y$ lattice can instead provide two minima of vertical beam size in one straight section. As the brightness of undulator radiation is proportional to the square of the period number, we can install two identical undulators with a phase shifter between them. In principle we could quadruple

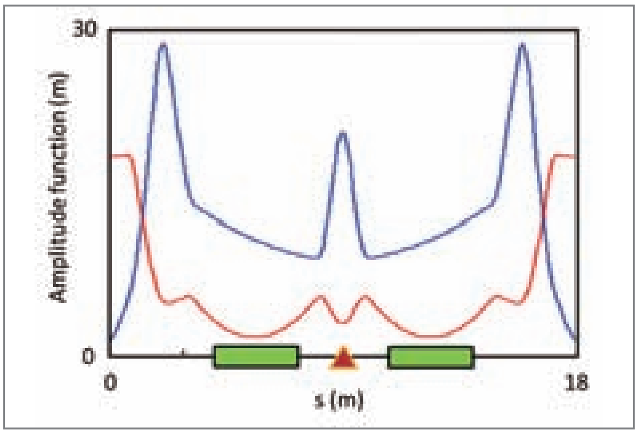


**Fig. 3:** A conceptual illustration of beam amplitude functions in the 12-m long straight section for the double mini-$\beta$y lattice. A red curve depicts the vertical amplitude function; a blue line depicts the horizontal amplitude function. The green rectangles denote two identical undulators; the triangle denotes the phase shifter.

**Table 2:** Major parameters of a double mini-$\beta$y lattice for the TPS storage ring, assuming 1 % emittance coupling.

| | |
|---|---|
| Natural emittance / nm rad | 1.6 |
| Straight section | 12 m x 6 + 7 m x 18 |
| Beam current / mA | 500 |
| Beam size at 12-m center (H/V) / μm | 164.1 / 5.3 |
| Beam size at 7-m center (H/V) / μm | 121.1 / 5.3 |
| Bunch length (RF @3.5 MV) / mm | 2.86 |
| Energy loss/turn, dipole / keV | 853 |
| Critical photon energy from dipole / keV | 7.12 |
| Maximum number of beam bunches | 864 |

the brightness of undulator radiation. Table 2 presents major parameters of the double mini-$\beta$y lattice for the TPS storage ring for comparison with the baseline design. Figure 4 shows a schematic layout of the double mini-$\beta$y lattice implemented in three 12-m straight sections of the TPS storage ring and phase-I insertion devices to be installed. The TPS storage ring is expected to be operated with the double mini-$\beta$y lattice after the commissioning work has been completed. Table 3 lists major parameters of insertion devices planned for the phase-I operation; Fig. 5 shows the predicted spectral performance. In the X-ray range, the brightness of TPS is about 1000 times that of TLS. A more detailed report on the phase-I insertion devices is available.[3]

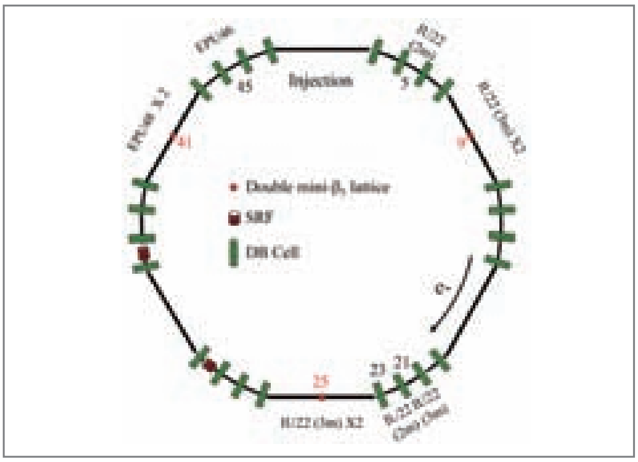


**Fig. 4:** Layout of a double mini-$\beta$y lattice with the installation plan of phase-I insertion devices in the TPS storage ring. The locations of double mini-$\beta$y lattice are indicated with red circles. The numbers shown in the sketch represent the port numbers of the phase-I beamlines.

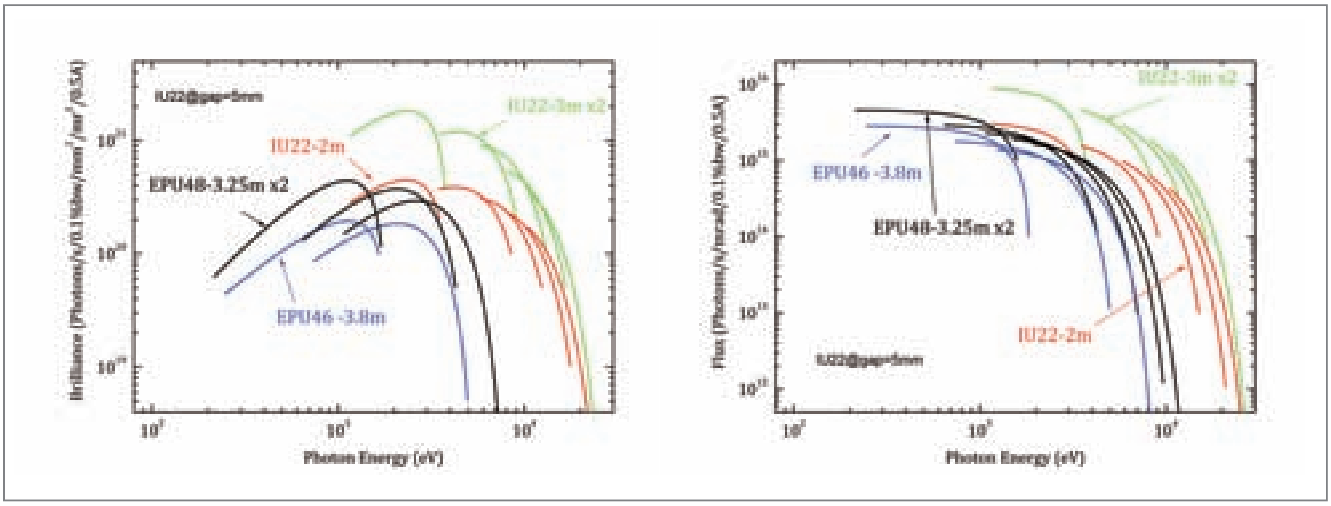


**Fig. 5:** Predicted spectral performance for phase-I insertion devices. The left plot depicts the brightness and the right one depicts the flux.

**Table 3:** Major parameters of insertion devices planned for phase-I operation (beam energy 3 GeV).

| | | EPU48 | IU22 | EPU46 |
|---|---|---|---|---|
| Photon energy / keV | HP | 0.23-1.5 | 5-20 | 0.26-1.5 |
| | VP | 0.42-1.5 | | 0.45-1.5 |
| Period length / mm | | 48 | 22 | 46 |
| $N_{period}$ | | 67 | 95 / 140 | 82 |
| Total length / m | | 3.436 | 2.58 / 3.57 | 3.89 |
| Gap / mm | | 13 | 7 (5*) | 13.5 |
| Total power (kW) | | 6.62 | 6.56*/9.67* | 7.49 |
| Power density (kW / $mr^2$) | | 24.25 | 42.48*/62.60* | 29.16 |

* final operational parameter

**Fig. 6:** An aerial view of the NSRRC site. The partially finished TPS building is clearly shown here. (courtesy of Natronal Space Organization, Taiwan)

## Current Status of TPS Construction

The civil construction of TPS building is behind schedule, but the central instrumentation area and the storage ring tunnel are completed. It is possible to provide partial occupancy for the installation and relocation of accelerator sub-systems according to the original schedule. The new guest house and activity center are completed. Figure 6 shows an aerial view of the NSRRC site and Fig. 7 shows the activity center for TPS.

The 150-MeV linac was contracted to Research Instruments GmbH. The delivery and acceptance test of the linac were completed in 2011 July. A test building was constructed to host this linac. The beam parameters of the linac have been measured, all within the technical specifications. The linac has operated smoothly since 2011 July. The entire linac system is planned to be removed to the TPS building in 2013 first quarter, with re-commissioning of the linac system after relocation. Figure 8 depicts the 150-MeV linac inside the shielding wall of the test building.

Several important components and sub-systems have been completed on schedule. PETRA cavities (normal conducting) in three sets, purchased from DESY, have been delivered and are ready for installation. At the beginning of the TPS commissioning, two PETRA cavities will be installed in the storage ring instead of the SRF cavities; after the quality of the vacuum attains the specified level, two SRF cavities will be installed to replace the PETRA cavities. Transmitters (300 kW, two sets) that will power the RF cavities passed the acceptance test in 2011 February. The first module of a SRF cavity was delivered to NSRRC in 2012 August. The assembly and integration of the first SRF module was completed in 2012 December. The high-power test of a SRF module was in 2013 January. Figure 9

**Fig. 7:** Exterior view of the new guest house and activity center.

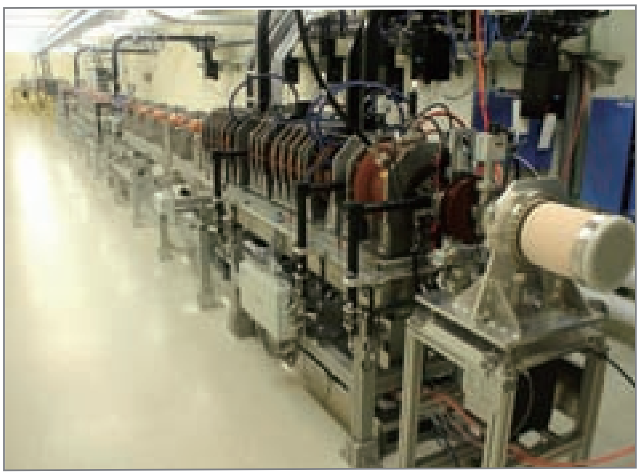

**Fig. 8:** 150-MeV linac inside the shielding wall of the test building.

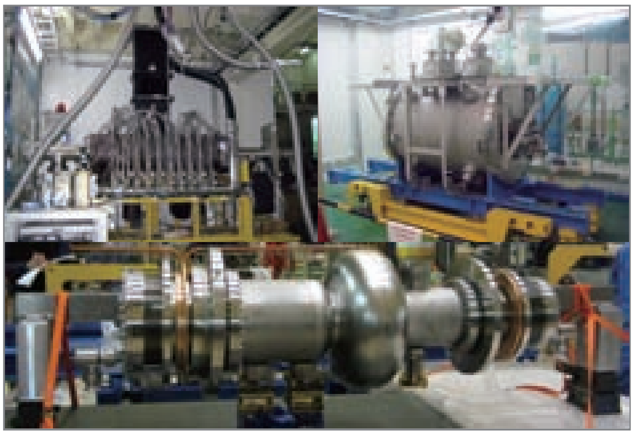

**Fig. 9:** Top left: a PETRA cavity ready for installation. Top right: the SRF module in the last stage of system assembly. Bottom: the KEK-B type SRF cavity without the cryogenic module.

shows a PETRA cavity and a SRF module. A 700-W liquid-helium cryogenic plant for the SRF system has been delivered and installed in a temporary test area; its acceptance test was completed in 2012 September. Figure 10 shows the refrigerator/liquefier of helium cryogenic system and the compressor in the cryogenic plant for TPS. The cryogenic system is scheduled to be moved to the TPS storage ring in 2013 February and re-commissioned in 2013 March. A detailed report of the design of the RF system for TPS is available in the previous report.[4]

The manufacture of all 14-m vacuum chambers for the arc sections in the storage ring has been completed. The assembly of the vacuum chambers with beam-position monitor (BPM) units, flanges, valves, vacuum pumps and gauges is progressing satisfactorily. Figure 11 shows the assembled vacuum chambers of one 14-m arc section. The fabrication and delivery of magnets for the booster and storage ring are tardy according to the original schedule by roughly one year, but tremendous efforts are being exerted to return to schedule. It is possible to overtake the original schedule and to complete the installation of magnets punctually. Figure 12 depicts the assembly of magnets and girders for one arc section. Two sets of in-vacuum undulators (IU22 - 2 m) have been delivered; their acceptance test was completed in 2012 August. Figure 13 shows an in-vacuum undulator (IU22) and the apparatus for field


**Fig. 10:** Left: The refrigerator/liquefier of helium cryogenic system. Right: compressor in the TPS cryogenic plant.

**Fig. 11:** Assembled vacuum chambers of one 14-m arc section. The upper halves of the magnets were removed for the installation of the vacuum chambers.

**Fig. 12:** Assembly of magnets and girders for one arc section.

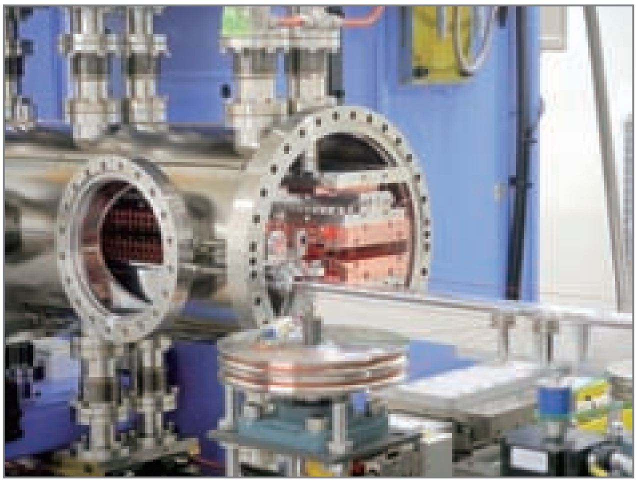

**Fig. 13:** Undulator (IU22- 2m) in vacuum with the apparatus for field measurements in situ.

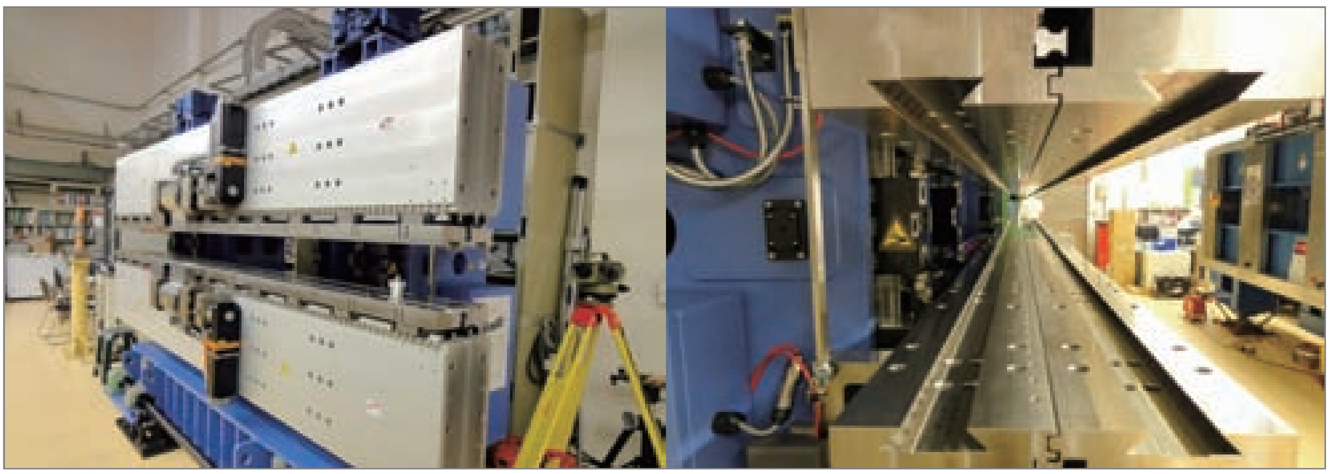

**Fig. 14:** EPU48 undulator in the measurement laboratory (magnet blocks not installed yet).

measurements in situ. Two units of elliptically polarized undulators (EPU48) were delivered by the end of 2012 November. Figure 14 depicts one such EPU48 undulator. The power supplies for the quadrupole and sextupole magnets were delivered on schedule in 2012 July. For beam diagnostics, the BPM electronics have passed their acceptance test in 2012 July.

Although the civil construction and fabrication of magnets are delayed, intensive efforts are being made to resume the planned schedule. Many sub-systems are on schedule. The commissioning of the accelerator is expected to begin in 2014 and be open to users in 2015.

**References**

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