PLANNING OF INSERTION DEVICES FOR THE 3-GEV TAIWAN PHOTON SOURCE*

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Abstract

The Taiwan Photon Source (TPS) is a 3-GeV storage ring with 24 straight sections for installation of insertion devices (ID), radio-frequency cavities (RF) and electron-beam injection. Most insertion devices are in-vacuum undulators to produce intense X-rays with a brilliance up to 1×10^{21} photons s^{-1} $mrad^{-2}$ mm^{-2} per 0.1 % bw. A superconducting wiggler is also necessary to provide higher energy in the medium-energy range of the TPS. The APPLE II elliptically polarized undulator and a long-period undulator provide a source with circular and any linear polarization and the VUV source. Projects to investigate a superconducting undulator and a cryogenic permanent-magnet undulator are launched for energies in a range 1.5 – 25 keV.

INTRODUCTION

TPS is a 3-GeV storage ring of medium energy with a circumference 486 m and 24 cells, and a Double Bend Achromat (DBA) (possibly to be replaced with a Quadratic Bend Achromat (QBA)) lattice. The theoretical minimum emittance is 1.7 nm rad in a chromatic section. The fundamental requirement of the 3-GeV TPS facility is to deliver synchrotron radiation of great quality over a broad spectral range, from the VUV and soft X-rays to hard X-rays. There are 21 straight sections (10.9 m × 3, 5.7 m ×18) in which TPS can accommodate insertion devices, but in the residual space in the SRF section can also be installed a superconducting wiggler and undulator. For the medium-energy ring, the undulator radiation source will be the main source of photon light, for which the periodic length must be as short as possible, which implies using high harmonics of the fundamental wavelength. The insertion devices should concurrently provide diverse photon sources for various scientific experiments, for which sundry insertion devices can be used to fulfill the range of photon energy between 0.02 keV and 120 keV, and also to provide varied modes of polarization on the TPS storage ring. The feasibility of developing novel insertion devices must therefore be considered for the operation of insertion devices in the phase III.

To ensure that the lifetime of the electron beam and the efficiency of injection are not diminished, the aperture of the vacuum chamber on a straight section must not be too small, but the magnet gap that depends on the beam duct dimension limits the field strength of the insertion devices. For this reason, superconducting insertion devices and in-vacuum undulators at room or cryogenic temperature [1] must be developed. For the outside-vacuum undulators, a conventional planar undulator or an elliptically polarized undulator can be used. High-field superconducting wigglers [2,3] are also necessary to provide photons with energy higher than 20 keV. A superconducting undulator [4,5,6,7] might be considered for installation in the storage ring. Here we describe the probable potential of insertion devices as a reference for the construction of a future light source.

We report here also the planning philosophy for insertion devices and the nature of insertion devices to be operated at TPS. The in-vacuum undulator has a periodic length 2.8 cm and a minimum magnetic gap 7 mm, but a cryogenic permanent-magnet undulator with a periodic length 1.8 cm at a magnet gap 5 mm will be developed to provide energy up to 20 keV. One long undulator or undulators with chicane of two types can be installed in a long straight section to provide a brilliance up to 1×10^{21} photons s^{-1} $mrad^{-2}$ mm^{-2} per 0.1 % bw for low photon energies or to enable experiments to be conducted in situ on a single beam line. Some elliptically polarized undulators (APPLE II structure) [8,9,10] are planned to provide light sources with circular and any linear polarization. One or a few superconducting wigglers with periodic length 4.8 cm and field strength 4.2 T will be

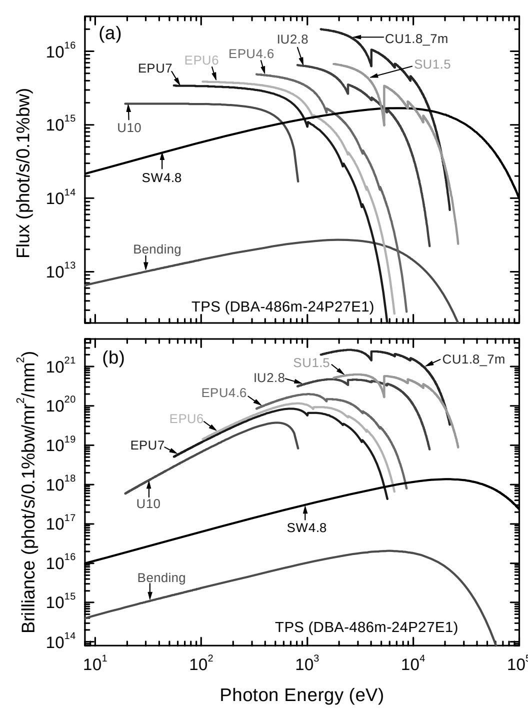

Figure 1: The spectrum of (a) flux and (b) brilliance at the TPS insertion devices for which the spectrum was calculated depends on parameters in Table I except the length of CU1.8.

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Table 1: Main Parameters of TPS Insertion Devices.

	EPU10	EPU7	EPU6	SW4.8	EPU4.6	IU2.8	CU1.8	SU1.5
Photon energy (keV)	0.02-0.9	0.07-4	0.12-5	10-100	0.4-6	1-12	1.3-20	2.5-25
Current (mA)	400	400	400	400	400	400	400	400
λ (mm)	100	70	60	48	46	28	18	15
Nperiod	35	50	58	31	76	125	194	100
By (Bx) (T)	1.0	1.0 (0.77) 0.93 (0.35)	0.9 (0.7) 0.85 (0.3)	4.2	0.76 (0.49) 0.66 (0.25)	0.9	1.34 (0.87)	1.5
Kmax	9.34	6.4 (1.7)	5.04 (3.92)	18.83	2.79 (1.07)	2.35	2.25	2.1
L (m)	3.5	3.5	3.5	1.5	3.5	3.5	3.5	1.5
Gap (mm)	15	15	15	12.5	15	7	5 (7)	5.6
Peak Power density (kW/mr^2)	12.3	8.0	8.7	45.7	9.0	43.4	90.2	67.3
Total power (kW)	8.0	7.7	6.4	59.8	4.0	6.5	14.5	10.2
Type	Hybrid	Pure	Pure	SC	Pure	Hybrid	SC	Hybrid

constructed to yield the critical energy 25 keV. A study of a superconducting undulator [11] with periodic length 15 mm and field strength 1.4 T is being launched to produce energies in a range 2.5 – 25 keV. Table 1 lists parameters of possible insertion devices in the TPS storage ring; Fig. 1 reveals the synchrotron radiation spectrum of these insertion devices. These insertion devices will have the standardized C-frame structure (length 2 m) and a control system. Two standard C-frame structures will maintain the insertion devices for length of 4 m. Because of budget limitations (the total budget is about USA$206 million), three In-achromatic superconducting wigglers (IASW, field strength 3.1 T with periodic length 6 cm and pole number 16) with SAXS, PX and the contract beam lines and one EPU4.6 with the beam line for magnetic experiments will be moved from TLS to be installed on the TPS during Phase I (commissioning phase). Several in-vacuum undulators with room-temperature and cryogenic permanent-magnet and APPLE II EPU undulators will be installed during phase II (five years after commissioning). If the superconducting undulator is developed successfully, it will be installed during phase III (ten years after commissioning).

IN-VACUUM UNDULATOR AT ROOM AND CRYOGENIC TEMPERATURES

The In-vacuum undulator can provide a short-period length ID to obtain maximal photon energy. A periodic length 28 mm (IU2.8), field strength 0.9 T at room temperature and a magnet gap 7 mm are selected to provide energy in a range 1-12 keV. The field strength of the hybrid structure is 10 % larger than that of the pure structure, but, because the pure structure is easily constructed and the integral field variation can be kept as small as possible when the magnet gap is changed, a pure structure is selected, with dimensions 52×7×22.5 mm^2 of the magnet block. A cryogenic permanent-magnet undulator with a periodic length 18 mm (CU1.8) has a potential for the TPS storage ring. This magnet can increase the photon energy up to 20 keV. The material of the permanent magnet is 50 BH NdFeB for which B_r = 1.58 T and H_c = 3000 kA/m, at a temperature 148 K. The iron pole material is vanadium permadur; the magnet array is shown in Fig. 2. According to Table 1, the spectrum of the IU2.8 (length 3.5 m) and CU1.8 (length 7 m) was calculated for the TPS bare lattice, as shown in Fig. 1.

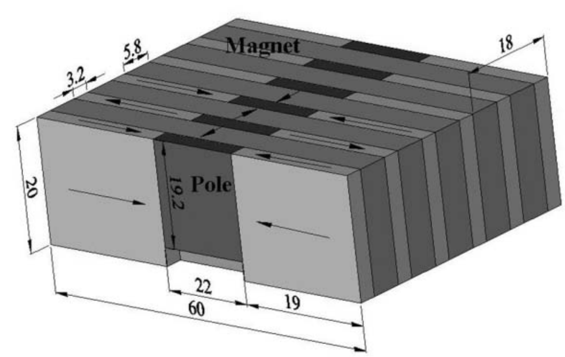

Figure 2: Schematic drawing of the magnet array of the cryogenic permanent-magnet undulator.

APPLE-II ELLIPTICALLY POLARIZED UNDULATORS

The elliptically polarized undulator (APPLE-II structure) provides variously polarized light - vertically and horizontally linearly polarized, right and left circularly polarized, and linearly polarized at other angles [9]. The EPU10, EPU7, EPU6 and EPU4.6 are thus planned to provide energies from 20 eV to 6 keV. As the region of homogeneous field (magnetic field roll-off) of the distributions of horizontal and vertical fields of the APPLE-II structure is too short, various magnet block arrangements have been investigated to enlarge the region of homogeneous field. The magnetized tilt angle (10 deg) in the V-block seems optimal to enhance the region of homogeneous field, and the variation of the multipole components is smaller than that of other methods when the phase is altered. Although the field strength of the hybrid structure is 8 % larger than that of the pure structure, but, because to maintain a small integral field variation when the magnet gap and phase are altered, a pure magnet structure is selected. The dimensions of the optimized magnet block are listed in Table 2. Seven and nine blocks were assembled on the individual keeper module for ease of assembly of the four magnet arrays on the girder. To achieve the maximum merit of flux on varying the gap, the phase should be altered as a function of that magnet gap. The end-pole design will be optimized to maintain a variation of small integral field strength when the phase and magnet gap are altered. Figure 1 shows spectral features of the various planar elliptically polarized undulators.

Table 2: Optimized dimensions of magnet blocks in the various elliptically polarized undulators

	EPU4.6	EPU7	EPU9	EPU10
Lx (mm)	40	40	40	40
Ly (mm)	11.5	13.5	22.5	25
Lz (mm)	32	40	50	50

SUPERCONDUCTING WIGGLERS AND UNDULATORS

The superconducting insertion devices will provide a strong field with a small periodic length and produce high-energy photons. The superconducting wiggler and undulator are therefore planned to be installed in the TPS. The superconducting wiggler provides photon energies from 20 keV to 120 keV, and the superconducting undulator provides photon energies 2.5 – 25 keV. In our plan, the superconducting wiggler (SW4.8, length 1.5 m) with a periodic length 4.8 cm is considered for development to provide a magnetic field of strength 4.2 T. The SW4.8 will provide a large ratio F/P (photon flux F, radiation power P) compared to other superconducting wigglers. Figure 1 reveals the flux and brilliance of the SW4.6 (length 1.5 m) that has a critical energy 25 keV. Both high-field and low-field superconducting NbTi wire will be used to construct the coil. To decrease the deflection parameter *k* value, we shall try to decrease the periodic length to create the same field strength. A superconducting undulator with periodic length 1.5 cm and maximum field 1.4 T has also been launched [11]. A preliminary design of the 40-pole prototypical magnet has been implemented and constructed that was wound with rectangular wire of dimensions 0.77 x 0.51 mm^2 and round wire of 0.44 mm. The ratio of Cu/SC is 1.3 and 0.9, respectively. An even-pole design was selected for the superconducting wiggler and undulator. In the future, superconducting wire of MgB_2 and the HTS BSCCO wire will have a potential for winding the coils for the superconducting wiggler and undulator. The main issue of the superconducting undulator is the heat load on the beam duct from the radiation of the bending magnet and the image current. A long bunch length and a soft-end dipole magnet are necessary to decrease the heat load. During phase I, the old In-achromatic superconducting wigglers (IASW) that have 16 poles with periodic length 6 cm and maximum field strength 3.1 T will be installed, but in Phase II or III the SW4.8 will replace the IASW to enhance the photon flux for a photon energy above 20 keV.

CONCLUSION

In the 3-GeV TPS, at least one superconducting wiggler is necessary to provide a photon energy beyond 20 keV. An in-vacuum undulator with room-temperature and cryogenic permanent-magnet is the key radiation source for the 3-GeV facilities to provide hard x-rays. If practicable, the superconducting undulator can extend the photon energy to 25 keV; a superconducting elliptically polarized undulator [4] has a potential to be constructed for circularly polarized light on using the first harmonic energy that can decrease the waste head load on the beam line.

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