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SPS-II: A 4th GENERATION SYNCHROTRON LIGHT SOURCE IN SOUTHEAST ASIA

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Abstract

Upon its completion, Siam Photon Source II (SPS-II) will be the first 4th generation synchrotron light source in Southeast Asia. The 3.0 GeV, 327.5 m storage ring based on the Double-Triple Bend Achromat lattice will have the natural emittance of 0.97 nm·rad. The storage ring includes 14 long and 14 short straight sections for insertion devices and machine subsystems. The beam injection will be performed by a 150 MeV linear accelerator and a full-energy concentric booster synchrotron sharing the same tunnel with the storage ring. In the first phase, there will be 7 insertion devices and 7 associated beamlines with the end stations for different techniques utilizing synchrotron radiation from 80 eV to 60 keV. High-energy and high-brightness radiation generated by the new light source will serve as one of the most powerful analytical tools in the region for advanced science and technology research.

INTRODUCTION

Siam Photon Source II (SPS-II), when completed, will be among the most important scientific research infrastructures in Southeast Asia. It will play a significant role in supporting Thailand, as well as other ASEAN countries, in the transition to research and innovation-driven economy. The facility will be available to synchrotron radiation users from within Thailand, from all the ASEAN countries, and from around the world. This new light source will strengthen scientific community in the region by providing high-energy and high-intensity synchrotron light for both academic and industrial research. The facility will be constructed at the Eastern Economic Corridor (EEC) area in the EECi (EEC of innovation) district in Rayong Province in order to provide support to the high-tech industry in the area. SPS-II will provide better photon beam characteristics compared to the existing Siam Photon Source (SPS) and will be globally competitive for the growing user community in the region.

SPS-II MACHINE OVERVIEW

Though it is a new machine, SPS-II has some constraints on its size due to the available area of its designated location and financial reasons. Medium size storage ring with the circumference below 400 m is sufficient to provide photon beam with emittance below 1.0 nm·rad while being able to accommodate more than 20 Insertion Device (ID) beamlines.

SPS-II accelerator complex consists of three main components as illustrated in Fig. 1: a 150 MeV injector linac, a 3 GeV booster synchrotron, and a 3 GeV electron storage ring. Electrons are supplied to the linac by a thermionic pulsed DC gun. The 3 GeV storage ring has a circumference of 327.5 m and the electron beam emittance of 0.97 nm·rad. The lattice is a Double Triple Bend Achromat (DTBA) lattice which was first proposed for the upgrade of Diamond Light Source [1]. The storage ring consists of 14 DTBA cells, resulting in 14 long and 14 short straight sections. Maximum stored beam current will be 300 mA [2].

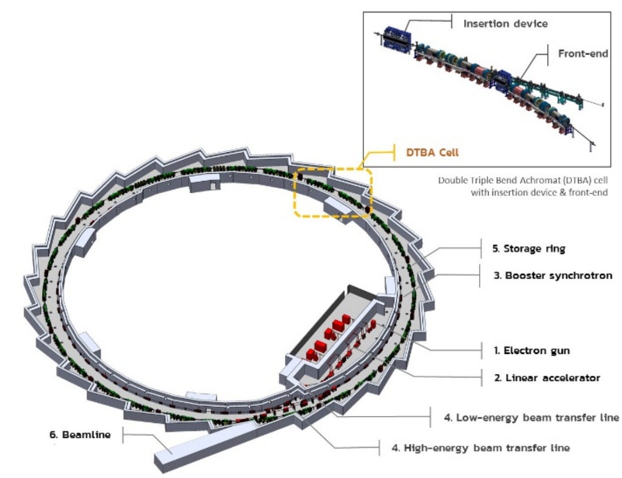

Figure 1: SPS-II accelerator complex.

In the process of designing SPS-II, we focus on three main aspects: performance, feasibility, and productivity. The DTBA lattice is adopted to achieve the beam emittance below 1.0 nm·rad, and to have an extra 3.10-m short straight section in the middle of DTBA cell in addition to the 5.02-m long straight section. As such, productivity or space usage reaches over 35%. The middle straight section can comfortably accommodate an undulator with the length of up to 2 m. To ensure manufacturing feasibility, requirements and specifications of the main machine components are kept moderate, for example, the required magnetic field and magnetic field gradient of the SPS-II magnets are modest and the magnets can be manufactured using available technologies.

The photon beam delivered by the much smaller electron beam of SPS-II compared to that of SPS provides higher brightness and coherence fraction. The new lattice cell offers twice the number of available straight sections for IDs per cell. Like most recent synchrotron light sources, the main radiation sources will be IDs, however, Infrared (IR) radiation can be extracted from SPS-II bending magnets.

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IR beamline will be constructed and operated in the second phase of SPS-II operation. Improvement on photon brilliance of SPS-II compared to that of SPS can be seen in Fig. 2.

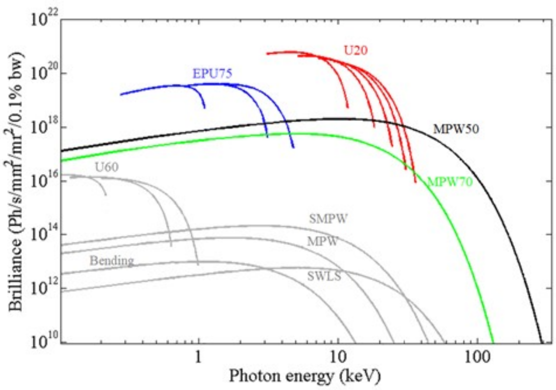

Figure 2: Calculated brilliance of SPS (grey) and SPS-II sources.

150-MeV Linac

The 150-MeV linac for SPS-II is designed such that the total length is below 25 m and is compatible with the 119-MHz RF system of the booster synchrotron and the storage ring. The SPS-II linac consists of a triode gun with 119-MHz voltage modulation at grid level for producing a chopped beam, a subharmonic pre-buncher operating at 476 MHz, an S-band buncher operating at 2,856 MHz, and S-band accelerating structures, as presented in Fig. 3. The normalized beam emittance is below 50 mm·mrad with the RMS energy spread below 0.5%. Repetition rate ranges from 1 to 5 Hz with the nominal repetition rate of 2 Hz.

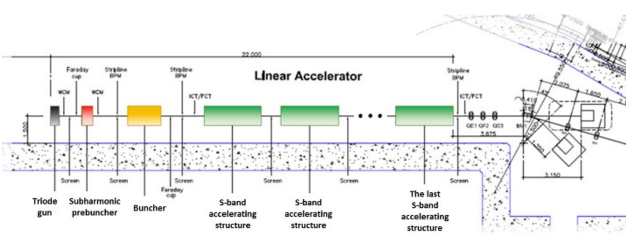

Figure 3: Components of the SPS-II 150-MeV linac.

Booster Synchrotron

In order to minimize the cost of building construction, the SPS-II booster synchrotron will be installed in the same tunnel as the storage ring. The average distance between the booster ring and the storage ring is 3.6 m. This should be sufficient to mitigate the stray fields from booster magnets, and comfortable for installation and transportation of magnets, girders, vacuum chambers, and other equipment. The booster synchrotron comprises of 40 modified FODO cells with combined function magnets. There are 8-fold symmetric lattices, each of which consists of 5 FODO cells. Small beam emittance of 5.87 nm·rad at 3 GeV can be achieved. With this emittance, high injection efficiency can be realized for top-up operation.

RF System

The RF frequency of 119 MHz is chosen for both the SPS-II storage ring and booster synchrotron due to the experience with the existing machine. It also requires less RF voltage and power consumption. In addition, the Low-Level RF unit can be simplified. During the first phase operation, 5 cavities will be used in the storage ring and 4 cavities will be used in the booster synchrotron with the total voltage of 1.5 MV and 1.2 MV, respectively [3]. The RF accelerating voltage can be increased up to 1.8 MV when the straight sections of the storage ring are fully occupied by IDs. The RF acceptance of the storage ring is greater than 4.2%, which is sufficient for the beam lifetime during the first phase operation. All RF cavities are normal conducting, and the RF power is supplied by solid-state RF amplifiers in combination with Digital Low-Level RF (DLLRF) controllers. Third harmonic cavities (Landau cavities) will be installed to suppress beam instabilities as seen in Fig. 4.

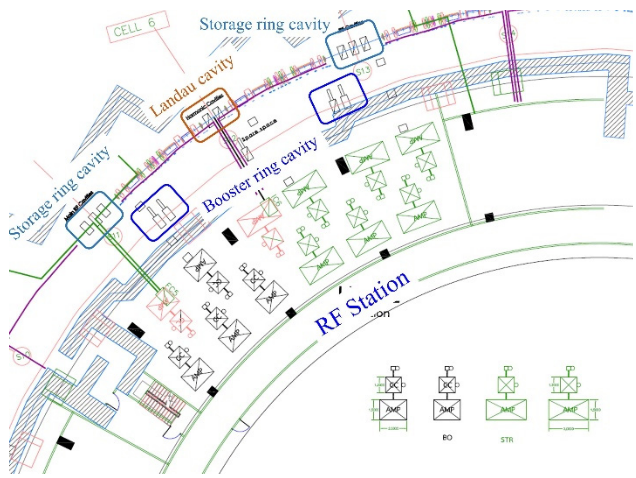

Figure 4: RF system of SPS-II.

Magnet System

Dipole magnets for SPS-II storage ring have the dipole field of 0.87 T. Magnetic field gradient for quadrupole magnets ranges from 44 to 60 T/m [4]. Combined function dipole-quadrupole magnet is also used, with the quadrupole gradient of 26 T/m. The design of this combined function magnet is based on the offset quadrupole design of ESRF [5]. Storage ring magnets are made of AISI 1006 low-carbon steel. Fabrication tolerance of the magnet pole is controlled within 20 μm, which can be achieved by local manufacturing industry in Thailand using the wire-cut Electrical Discharge Machining (EDM) and grinding techniques. Corrector magnets and magnets for booster synchrotron are made of laminated steel. These magnets are designed in-house and will be manufactured within the country. Figure 5 shows magnets for half-cell of DTBA lattice in the SPS-II storage ring, for which prototype development is in progress.

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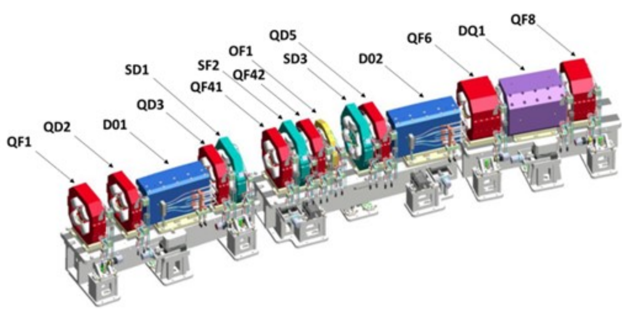

Figure 5: Magnets for half-cell of DTBA lattice.

Beam injection into the storage ring is executed with a Pulsed Multipole (PM) magnet [6], which is designed based on the Non-Linear Kicker (NLK) magnet developed for BESSY-II [7]. This kicker and the other pulsed magnets for SPS-II injection system will be designed and purchased as a turn-key system.

Mechanical Positioning System

The magnet girder of the SPS-II storage ring uses wedge mounts for precision alignment based on 3-2-1 alignment method, which requires three wedge mounts for Z-direction, two for Y-direction, and one for X-direction as shown in Fig. 6. The girder's top plate is designed and manufactured as precision surface with the flatness tolerance of 30 µm [8]. Requirement for girder-to-girder alignment tolerance is 100 µm.

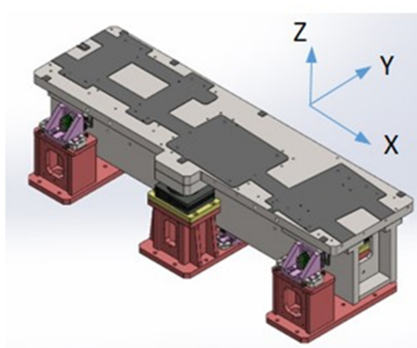

Figure 6: Magnet girder for SPS-II storage ring.

Vacuum System

Vacuum chambers for SPS-II are made of stainless steel due to its excellent strength and the availability of local manufacturing technology in Thailand (especially welding technology). Additionally, the vacuum chamber thickness is limited by the space available between the magnet poles, and thin stainless steel chamber is feasible to manufacture. Fabrication tolerance of the vacuum chamber is 1 mm/m with the taper inclination less than 1/10 and the step height less than 1 mm. All vacuum chambers for the magnet sections will be baked in the laboratory and installed afterwards into the storage ring under vacuum. The chamber for straight sections will be evacuated and baked in the tunnel. Non-Evaporable Getter (NEG) and sputter ion pumps will be used to obtain the required pressure of 1×10^{-9} Torr. Therefore, the chamber's inner surface needs to be treated as clean as possible to reduce the residual gases from both static and dynamic outgassing.

Photon Beamlines

During the first phase operation, 4 types of IDs will be installed for the planned 7 beamlines. The IDs include an elliptically polarized APPLE-II undulator, a multipole wiggler, 3 in-vacuum undulators, and 2 in-vacuum multipole wigglers. These will cover a wide range of experimental techniques, as summarized in Table 1. The experimental techniques chosen are based on the past utilization of SPS, which reflects the present needs of Thai and ASEAN users, as well as on future trends of scientific development. These techniques can be utilized for several applications including polymers, biomedicals, food, agriculture, energy, industrial materials, environment, forensics, archaeology, and palaeontology. Lower beam emittance, higher beam current, and the use of in-vacuum undulators in SPS-II will provide researchers with X-rays that is more than 1 million times more intense than currently achievable with SPS. This will also provide new scientific opportunities to researchers and help to develop excellent research, innovation, and industry in the region.

Table 1: IDs and Beamlines for SPS-II

IDs	Beamlines	Techniques
EPU64	HRSXS	PES, ARPES, XPS, PEEM, NEXAFS, XMCD
MPW70	TXAS	XANES, EXAFS, XRF
MPW50	HXAS	XANES and QEXAFS, XRF, XES
U20	SWAXS	SAXS, WAXS USAXS, GISAXS
U20	HRXRD	XRD, High Resolution XRD, XRD imaging
MPW50	XMCT	micro-tomography
U20	MX	micro-focused MX MAD and SAD

PROTOTYPE DEVELOPMENT

To enhance manufacturing capability within the country and prepare for the construction of SPS-II, collaboration on prototype development has been established between Synchrotron Light Research Institute (SLRI) and Thai industries. This includes the prototype of vacuum chambers, magnets, and girders for the half-cell of DTBA lattice in SPS-II storage ring as shown in Fig. 7. Necessary measurements and tests of the prototype is planned to be completed in 2023 before the design can be finalized and the mass production can start.

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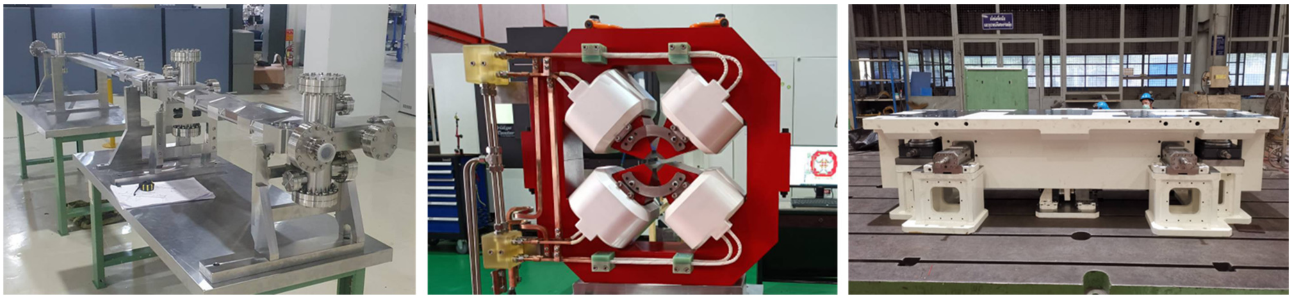

Figure 7: Prototype of vacuum chambers, magnets, and girders for the half-cell of DTBA lattice.

BUILDING DESIGN

As SPS-II will be situated in the Education zone of EECi in the area of Vidyasirimedhi Institute of Science and Technology (VISTEC), it will be surrounded by both industries and academics. Figure 8 shows the SPS-II facility during the first phase operation, which consists of the synchrotron light source, an administration and user service building, a guest house, a utilities building, and magnet, vacuum, and RF laboratories. Machine Instrument Area (MIA) will be located on the first floor of the synchrotron light source and Control Instrument Area (CIA) will be on the second floor. The magnet, vacuum, and RF laboratories and the utilities building will be built close to the synchrotron light source for convenience and easy access when any support is needed.

With the vertical size of electron beam in the storage ring of 2.7 µm at the middle straight section, orbit stability requirement for SPS-II is therefore ~0.27 µm which is quite challenging. Building design of SPS-II needs to consider several factors to keep a good performance of the machine. The ground of storage ring and beamlines will be isolated from external mechanical vibration and disturbance. The floor vibration is to be controlled within 30 nm in the frequency range of 4 - 100 Hz. The floor deformation or settlement is to be less than 100 µm/10 m per year. The building will conform to VC-E vibration criteria in wide-band with the maximum level of flow velocity of 3.12 µm/s. Air temperature variation in the accelerator tunnel and optical hutch is controlled within ± 0.1 °C.

CONCLUSION

SPS-II project aims to serve the user community in Southeast Asia and around the world with new opportunities for both research and industry. The design concepts focus on the performance, feasibility, and productivity, where the DTBA lattice was chosen. SPS-II machine components and buildings have been designed. Prototype development of magnets, vacuum chambers, and girders for half-cell of the DTBA lattice is currently in progress. The SPS-II is planned to open for users in 2029.

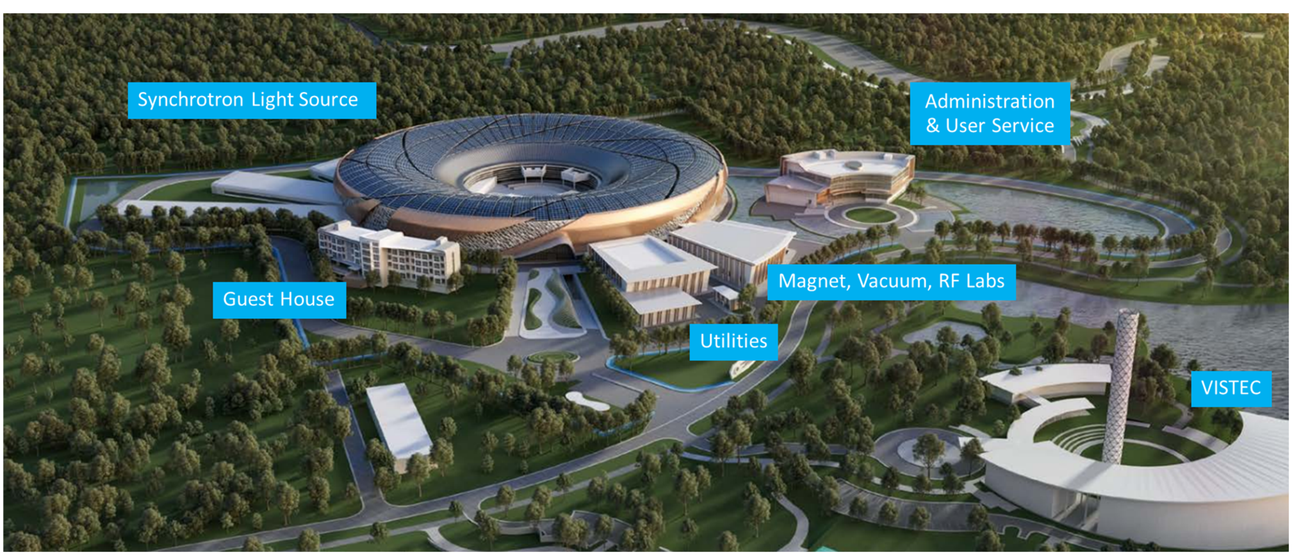

Figure 8: SPS-II facility.

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