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CONCEPTUAL DESIGN OF BOOSTER SYNCHROTRON FOR SIAM PHOTON SOURCE II*

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Abstract

A project on a 3.0 GeV Siam Photon Source II (SPS-II) has been started. The storage ring of SPS-II was designed to obtain an electron beam with a low-emittance below 1 nm-rad. The SPS-II injector mainly consists of a 150 MeV linac and a full-energy booster synchrotron. The booster synchrotron will be installed in the same tunnel as the storage ring, with a total circumference of 304.829 m. The proposed lattice of the booster contains 40 modified FODO cells with combined function magnets. This lattice achieves a small beam emittance less than 10 nm-rad at 3 GeV, which can provide a high injection efficiency for top-up operation. The conceptual design for SPS-II booster synchrotron is presented in this work.

INTRODUCTION

Synchrotron Light Research Institute (SLRI) is the one and only synchrotron light institute in Thailand and the largest in the Southeast Asia region to date, situated in Nakhon-Ratchasima, Thailand. It is the national synchrotron research institute called "Thai Synchrotron National Lab" in charge of the management, operation, and development of the synchrotron light source, namely, Siam Photon Source (SPS). The existing SPS machine is a dedicated 1.2 GeV synchrotron radiation source, which has been in operation for synchrotron radiation users since 2003.

Nowadays, there are several experimental techniques at SLRI available for Thai and international users in many areas of scientific research and industrial development. The increase in number of users brings attention to the possibility of constructing the new 3 GeV light source (SPS-II), which could provide synchrotron light with higher photon energy and more brilliant synchrotron light than that of the existing machine as plotted in Fig. 1. SPS-II will be located in the Eastern Economic Corridor of Innovation (EECi), in the Rayong province in Thailand.

At present, the SPS-II source is in the process of being designed. The storage ring of SPS-II with the circumference of 327.502 m is a Double Triple Bend Achromat (DTBA) lattice, which not only obtains a beam emittance below 1 nm-rad, but also provides the sufficient spaces for the insertion devices [1]. In order to save the cost of construction and operation, we decided to change the design of SPS-II injector from a full energy linac to an in-tunnel booster ring in 2020. A new design of SPS-II injector mainly consists of a 150 MeV linac as pre-injector and a 3.0 GeV booster synchrotron. The layout of SPS-II is shown in Fig. 2. This work shows the design concept of booster lattice and the results of beam dynamics simulation.

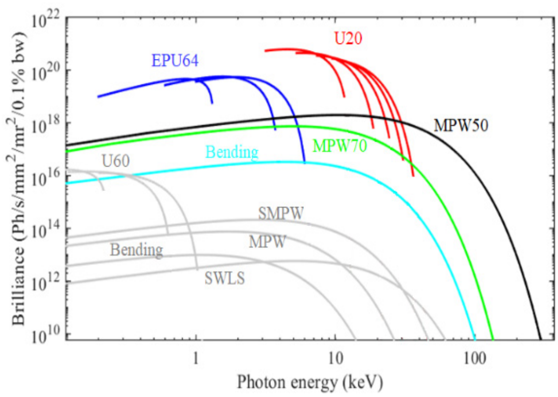

Figure 1: Brilliance of synchrotron light radiated as a function of photon energy from the existing 1.2 GeV machine (grey) and SPS-II (color).

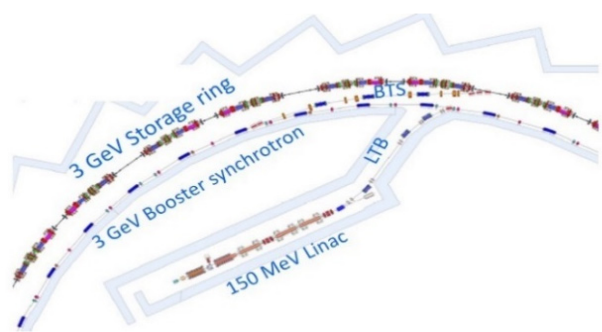

Figure 2: Layout design of SPS-II source with a 150 MeV linac and a 3 GeV booster sharing in the same tunnel as storage ring.

SPS-II BOOSTER SYNCHROTRON

The synchrotron sources with in-tunnel booster have been developed and successfully operated in many facilities such as SLS [2], SIRIUS [3], TPS [4], and ALBA [5]. For the in-tunnel booster, the booster synchrotron shares the same tunnel as the storage ring. The advantages are the low cost of lattice elements, the low power consumption, and the high-quality electron beam with low beam emittance. These features make in-tunnel booster particularly interesting. Although, the stray fields from the ramping booster magnets could potentially disturb an electron beam orbit in the storage ring, it could be minimized by using an H-type dipole for the booster bending magnet and providing a sufficient distance between the booster synchrotron and the storage ring. According to the main advantages mentioned above, we selected the in-tunnel booster for SPS-II.

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With an RF frequency of 119 MHz and a harmonic of 121, the total circumference is 304.829 m and the average distance between the booster and the storage ring is 3.6 m. This distance could be suitable to mitigate the stray fields from booster magnets, and comfortable for equipment installation and transportation. For SPS-II booster, an electron beam energy will be ramped from 150 MeV to 3 GeV with a repetition rate of 2 Hz.

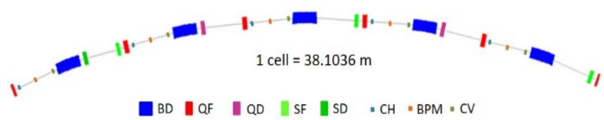

Figure 3: Layout of 1/8 of SPS-II booster synchrotron.

Table 1: Booster Magnets for SPS-II

Magnets	Length (m)	Radius (m)	Number
Combined Dipole (BD)	1.50	9.55	40
Combined Quad. (QF)	0.25	-	40
Quadrupole (QD)	0.20	-	16
Sextupoles (SF/SD)	0.20	-	24/8
Corrector (CH/CV)	0.10	-	40/40

The proposed lattice of the booster contains 40 modified FODO cells with combined-function magnets. There are 8-fold symmetric lattices, and each symmetric lattice consists of 5 cells of FODO lattice. A schematic diagram of the lattice is illustrated in Fig. 3. Booster magnets for SPS-II are summarized in Table 1. There are two types of combined function magnets, one is the combined dipole magnet (BD), and the other one is the combined quadrupole magnet (QF) that includes focusing quadrupole and sextupole fields. For the BD magnets, the terms of dipole field, defocusing quadrupole field, and the defocusing sextupole field are combined. The magnets in booster are in the process of design.

Table 2: Main Parameters of the SPS-II Booster

Parameters	Booster Synchrotron
Circumference	304.829 m
Beam energy	3.0 GeV
Relativistic factor (γ)	5870.85
Emittance	5.87 nm-rad
Nat. energy spread	0.091 %
Nat. chromaticity (ξ_x/ξ_y)	-23.63/ -10.31
Tune (Q_x/Q_y)	14.71/5.61
Momentum compaction (α_c)	1.674e-3
Energy loss per turn (U_0)	0.75 MeV
RF frequency	119.00 MHz
Harmonic number	121
Beam current	2 mA
Repetition rate	2 Hz

The working point is tuned by the focusing quadrupoles in the QF and the defocusing quadrupolar component in the dipoles BD. Since the defocusing quadrupole field component in the BD may have some field errors, an extra family of 16 pure defocusing quadrupoles (QD) placed beside the dipole magnet will be used to compensate. Thanks to the eddy current induced in the dipole vacuum chambers during energy ramping, the main field component generated is a sextupole term. Consequently, the sextupolar field component included in the BD magnet is necessary for chromaticity compensation. The free straight sections with non-zero dispersion regions are available for the injection/extraction, RF cavity installation, and the diagnostics components.

With the booster lattice presented, the nominal working point was selected at (14.71, 5.61), which could provide a low emittance of 5.87 nm-rad and a good dynamic aperture. The chromaticities were set to +1 in both planes by the focusing quadrupoles in the QF, the defocusing sextupolar components in the BD, and the families of sextupoles (SF and SD). The booster parameters for SPS-II are listed in Table 2 and the optical functions are shown in Fig. 4.

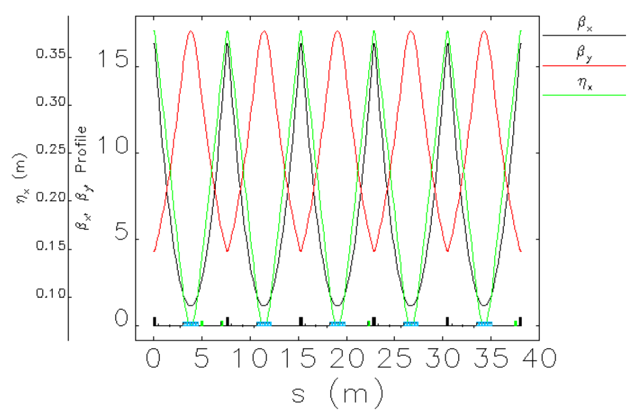

Figure 4: Optical functions for one symmetric lattice, (Maximum horizontal betatron functions = 16.3 m, maximum vertical betatron function = 17.1 m, and maximum dispersion function = 0.377 m).

DYNAMIC APERTURE AND LATTICE IMPERFECTIONS

At the nominal working point, the dynamic aperture tracked by the code Elegant is shown in Fig. 5(top). The dynamic aperture for the ideal machine is about ±30 mm in horizontal plane and ±12 mm in vertical plane, which is larger than that of the physical aperture as expected. The dynamic apertures of the lattice with and without errors are compared in Fig. 5(bottom).

Due to magnetic field errors and misalignments, the beam orbit will be perturbed. The closed orbit distortions can be simulated under the following assumptions. The imperfections in all magnets are composed of the misalignments of 160 µm with 0.8 mrad rolling errors for all magnets and 300 µm misalignment for BPMs. The excitation errors are 0.15 % for the combined function di-poles and 0.3 % for the quadrupoles and sextupoles. Also, the dipole

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field error is added by 2.4 %. For closed orbit correction, the system consists of 40 magnets for both horizontal (CH) and vertical (CV) correctors and 40 beam position monitors (BPMs). All the correctors and BPMs are located upstream of the bending magnet and next to the QF magnets. After correction, the close orbit distortions are ± 1.8 mm and ± 0.2 mm in horizontal and vertical planes, respectively.

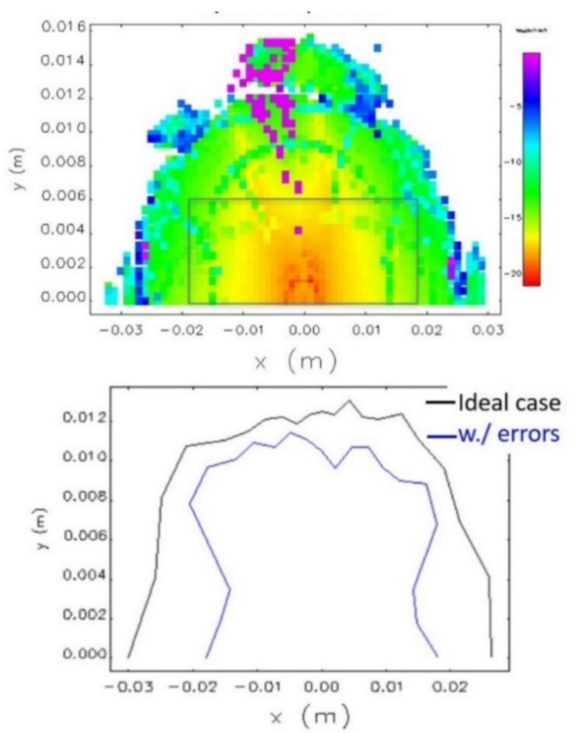

Figure 5: Booster dynamic aperture at the nominal working point (top) and dynamic aperture including the misalignment and lattice imperfections (bottom).

APERTURE REQUIREMENT

The aperture requirement for the booster can be defined by the injected beam parameters, energy variation, closed orbit distortions, and beam oscillations. A half-aperture or beam stay clear is expressed in Eqs. (1) and (2) for horizontal and vertical apertures, respectively.

$$A_x = 3\sqrt{\beta_x \varepsilon_x + (\eta_x \sigma_x)^2} + x_{COD} + \eta_x \delta_{osc} + x_{osc}, \quad (1)$$

$$A_y = 3\sqrt{\beta_x \varepsilon_x} + y_{COD} + y_{osc}. \quad (2)$$

For the Linac at 150 MeV, we assumed that the emittances $\varepsilon_{x,y}$ are 170 nm-rad and the energy spread σ_x is 0.5%. The close orbit distortions are x_{COD} and y_{COD} for horizontal and vertical planes, respectively. The energy variation (δ_{osc}) is ±2 % and the beam oscillations (x_{osc} and y_{osc}) are 3 mm and 1.5 mm in horizontal and vertical planes, respectively.

Figure 6 presents the estimated result of half-aperture requirement for the booster synchrotron. The maximum half-apertures are 19 mm in the QF magnets and 9 mm in the dipoles for horizontal and vertical planes, respectively. The booster vacuum chamber will be made of less than 1 mm thick stainless steel to minimize the eddy current component generated in the dipole vacuum chamber while ramping up energy. Therefore, the required diameters of the vacuum chambers are about 40 mm in the straight sections and 20 mm in the dipoles.

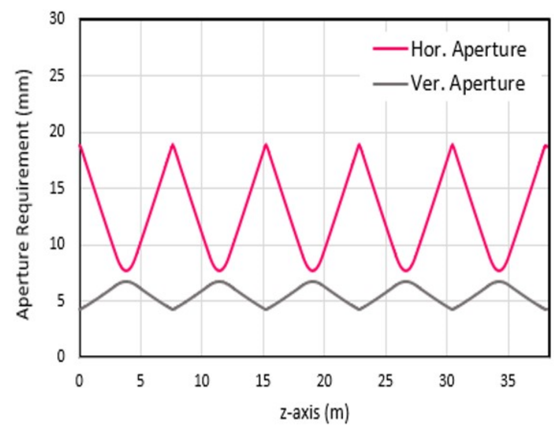

Figure 6: Half-aperture requirement for the SPS-II booster synchrotron.

CONCLUSION

The design for the SPS-II booster synchrotron is proposed. The lattice of the booster contains 40 modified FODO cells (8-fold symmetry) with combined function magnets. The low beam emittance of 5.87 nm-rad can be achieved to provide the high injection efficiency for top-up operation. The vacuum chamber will be round shaped and made from stainless steel, with a thickness of less than 1 mm and with diameters of about 40 mm and 20 mm in the straight sections and in the dipole magnets, respectively. Nonlinear effects during the energy ramp from 150 MeV to 3 GeV are in the process of being calculated.

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