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DESIGN AND OPTIMIZATION OF FULL ENERGY INJECTOR LINAC FOR SIAM PHOTON SOURCE II

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Abstract

The new Thailand synchrotron light source, Siam Photon Source II (SPS-II), has been designed based on a 3 GeV storage ring with a Double-Triple Bend Achromat (DTBA) lattice and a full energy injector linac. The linac consists of an S-band photocathode RF gun, C-band accelerating structures and two magnetic chicanes. In addition to its main function as the storage ring injector, the linac is capable of producing sub-picosecond electron bunches for additional short-pulse beamlines at the end of the linac. The linac also has a potential to become a driver of a soft X-ray Free Electron Laser (FEL) operating adjacent to the storage ring. In this paper, start-to-end simulations of the full energy linac are presented. Optimization was performed in order to fulfil requirements for both storage ring injection and short pulse generation.

INTRODUCTION

Siam Photon Source (SPS) is the biggest synchrotron light source in South East Asia and it has been operated with 1.2 GeV beam energy and 41 nm·rad beam emittance. The SPS storage ring is composed of four Double Bend Achromat (DBA) cells. The SPS has been upgraded to serve the user community with higher quality of synchrotron radiation including installation of four insertion devices (IDs) in all available straight sections of the storage ring. As the user community keeps growing in recent years, a new synchrotron light source with better performance and higher capacity of IDs is required.

A future 3-GeV storage ring, SPS-II, has been designed utilising DTBA lattice with the ring circumference of 321.3 m and beam emittance of 0.96 nm·rad aiming for higher photon flux and higher capacity of beamlines [1]. In terms of an injector for SPS-II, a full energy linac has been considered according to its potential to be operated as both a storage ring injector and a driver of short-pulse beamlines. Additional undulators can be installed at the end of the linac to establish soft X-ray FEL facility in the future.

FULL ENERGY LINAC DESIGN

The full energy linac for SPS-II was designed to be located in an underground tunnel. The design includes bunch compressors for shortening electron bunch length to generate sub-picosecond electron bunches which are required for the short-pulse beamlines and the future FEL. The Majority of accelerating structures in the linac was chosen to utilise high-gradient C-band structures developed for SACLA [2] to shorten the length occupied by the accelerating structures and make room for two bunch compressors in the linac. The layout of the linac including a transfer line (TL) of SPS-II is shown in Fig. 1. Pre-injector (L0) mainly consists of an S-band photocathode RF gun, a booster linac consisting of two S-band accelerating structures (L0S1 and L0S2), two C-band structures and an X-band structure. A photocathode gun operating at repetition rate of 60 Hz was chosen. Copper was chosen as a cathode material due to long lifetime and fast response time. Hence, a UV laser is required for the photoemission. A laser system for the injector consists of an IR oscillator laser, regenerative amplifiers and a third harmonic generator. The X-band structure is used to linearize longitudinal phase space for better bunch compression. The main linac consists of C-band structures and quadrupoles. The main linac is separated into two parts, L1 and L2. There are two bunch compressors based on a four-dipole chicane. The first bunch compressor (BC1) is used for bunch compression at low energy (~200 MeV). The second bunch compressor (BC2) performs bunch compression at high energy (~1.6 GeV). The length of the linac from the photocathode gun to the end of L2 is about 160 m. The electron beam from the linac is transferred through the TL to the storage ring on the ground floor.

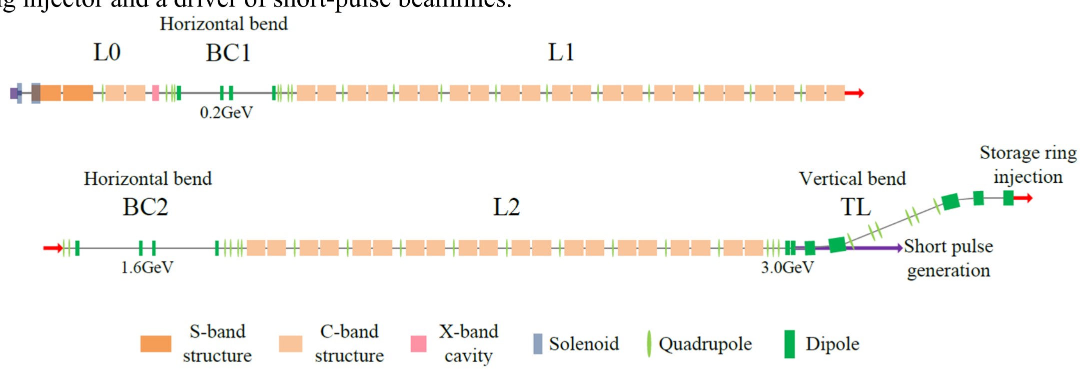

Figure 1: Layout of a full energy injector linac for SPS-II including a vertical transfer line to the SPS-II storage ring.

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START-TO-END SIMULATION

Beam dynamics of the SPS-II full energy injector linac was investigated by performing start-to-end simulations. The linac is separated in two sections (1) low beam energy section (<140 MeV), which is a part of L0 from the RF gun to the second S-band structure L0S2, and (2) high beam energy section (>140 MeV), which includes all components after L0S2. Space charge effects dominate at low beam energy and they are weaker as the beam energy rises. As the beam energy is higher and the bunch length is shorter, coherent synchrotron radiation (CSR) dominates and induces emittance growth, especially at the bunch compressors. Simulations of the low energy section were performed with ASTRA [3]. Simulations of the high energy section were performed with ELEGANT [4]. Optimisations were done in each section separately to achieve desirable beam parameters. A case with high bunch charge of 1 nC will be presented to investigate the upper limit performance of the injector.

Low Beam Energy Section

The ASTRA simulation was carried out from the cathode to the end of the S-band structure L0S2. The layout of the low beam energy section is shown in Fig. 2. The first solenoid is placed at the gun exit for controlling the beam waist position. The other solenoid is for beam focussing in the booster linac. Field gradient of the RF gun, magnetic field strength of the first solenoid and position of the first S-band structure L0S1 were optimised employing the emittance compensation technique in order to reduce the transverse beam emittance. The result from ASTRA is shown in Fig. 3. The normalised transverse emittance can be reduced to about 1 μm·rad and the beam size can be controlled nicely.

Figure 2: Layout of low beam energy section of the SPS-II pre-injector.

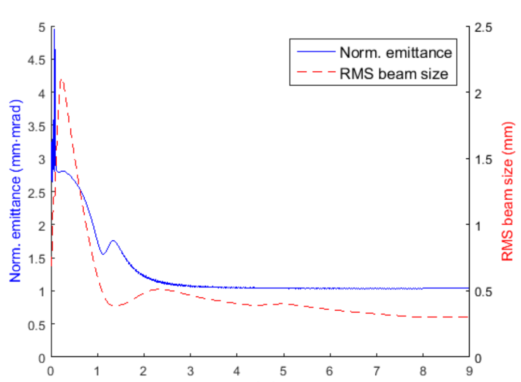

Figure 3: Normalised transverse emittance (blue, solid line) and beam size (red, dashed line) from the ASTRA simulation of the low energy beam section.

High Beam Energy Section

The simulation in the high beam energy section started with matching of linac lattice from the first C-band structure in L0 to the end of L2 and the vertical transfer line. The lattice matching was done to achieve beta function below 50 m and minimum horizontal beta function at the last dipole of both bunch compressors. The minimisation of horizontal beta function is for reducing emittance growth due to CSR. After lattice matching, the beam distribution from low beam energy section was used for particle tracking through the end of the linac. The optimisations of this section were done in order to find the configuration of the linac that gives proper beam parameters such as beam emittance and bunch length for storage ring injection and short pulse generation.

Since the linac will be mainly operated as an injector for the storage ring in the early stage of the SPS-II project, two modes of operation of the linac are presented in this paper. The first mode is an injection mode aiming to inject the beam from the linac to the storage ring only. The other mode, full operation mode, was investigated as one of the options for operating both storage ring beamlines and short-pulse beamlines in the later stage of the project. This mode aims to shorten electron bunch length to below 200 fs for short pulse beamline and storage ring injection.

Injection Mode Bunch compression is not utilised at full potential in this mode. Phase of C-band structures in L0 was set close to on-crest to maintain the bunch length at about a few picoseconds with reasonable transverse beam emittance and energy spread. The TL was designed as a vertical achromatic bend of total angle 22°. Layout and beam optics of the TL can be seen in Fig. 4. Beam parameters at the end of the TL are listed in Table 1. Since the injector was driven by the photocathode RF gun, the transverse emittance is much smaller than the transverse emittance from a booster synchrotron.

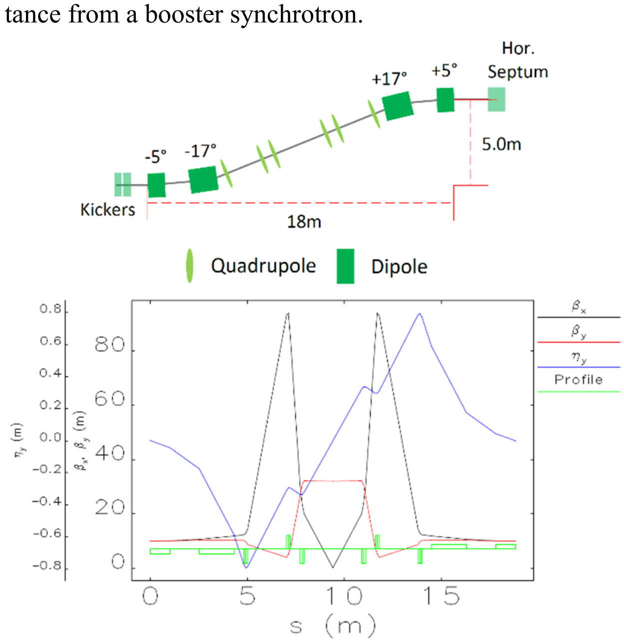

Figure 4: Layout of the TL (top) and optics function along the TL (bottom).

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Table 1: Electron Beam Parameters at Transfer Line End of Injection Mode

Parameter	Value
Beam energy [GeV]	3.04
Transverse emittance (hor./ver.) [nm·rad]	0.24/0.26
Normalised emittance (hor./ver.) [μm·rad]	1.45/1.57
Beam size (hor./ver.) [μm]	45.7/59.0
Bunch length (rms) [ps]	4.57
Energy spread [%]	0.45

Full Operation Mode The optimisations were done to achieve the bunch length shorter than 200 fs for short-pulse beamlines, to obtain beta functions below 50 m along the linac, and to get local minimum horizontal beta at the last dipole of both bunch compressors. The compressed bunches are transferred and injected to the storage ring. Beam parameters for short-pulse beamlines at the end of linac and for storage ring injection at the end of the TL are listed in Table 2. Longitudinal phase space and longitudinal distribution at the end of the linac can be seen in Fig. 5. Bunch length of 149 fs and peak current of 3 kA are achievable for the short pulse beamlines.

Table 2: Electron Beam Parameters at Transfer Line End of Full Operation Mode

Parameter	After L2	After TL
Beam energy [GeV]	3.03	3.03
Transverse emittance (hor./ver.) [nm·rad]	0.48/0.18	0.54/0.18
Normalised emittance (hor./ver.) [μm·rad]	2.83/1.06	3.19/1.07
Beam size (hor./ver.) [μm]	54.0/40.8	99.2/42.2
Bunch length (rms) [fs]	149	950
Energy spread [%]	0.12	0.12

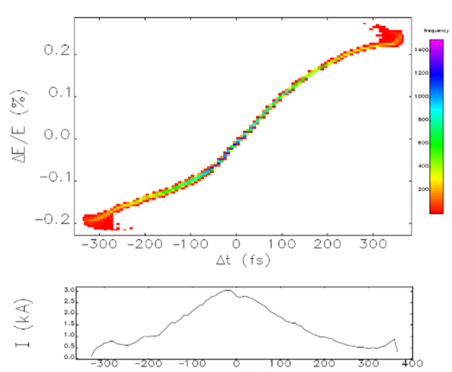

Figure 5: Longitudinal phase space (top) and distribution (bottom) after L2.

STORAGE RING INJECTION

Beam injection and beam top-up of the SPS-II storage ring were designed to utilise a pulsed multipole magnet (PM). The injection scheme based on the PM was chosen due to its simplicity, ease of operation and maintenance, and small perturbation to the stored beam. The PM in the SPS-II storage ring is placed in the first long straight section at 2.1 m downstream of the centre of the straight. The PM injection scheme requires the beam to arrive at the PM with the horizontal amplitude of 9 mm and the injection angle of 3 mrad. Therefore, a horizontal septum magnet is placed downstream the transfer line and is located at the middle of the injection straight. The injected beam exits from the septum with 3 mrad kick angle at the injection position, which is 15 mm away horizontally from the stored beam as shown in Fig. 6. With the bunch charge of 1 nC from the 60-Hz injector, duration of the initial fill is about 6 s assuming lossless injection. The injected beam delivered by the injector which achieved small emittance is feasible with this scheme.

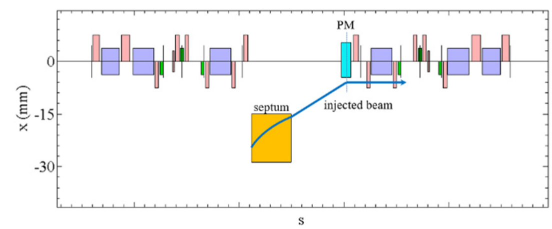

Figure 6: SPS-II storage ring injection based on a PM.

CONCLUSION

The design of the SPS-II full energy injector linac was presented. Start-to-end simulations and optimisations of the linac in injection mode and full operation mode give promising results for storage ring injection. For short-pulse beamlines, the 3-GeV beam with the bunch length of 149 fs, normalised emittance below 3 μm·rad and energy spread of 0.12% can be obtained by the SPS-II full energy linac. Optimisations of the linac should be performed further by applying more advanced optimisation algorithm such as Multi-Objective Genetic Algorithm (MOGA). Beam injection and top-up process should be studied in more details.

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