PULSED MAGNETS DEVELOPMENT FOR THAILAND'S SPS-II

T. Yan*, S. Boonsuya, S. Jummunt, P. Klysubun,
A. Kwankasem, T. Leetha, W. Phacheerak, T. Phimsen,
S. Prawanta, T. Pulampong, P. Sudmuang, P. Sunwong
Synchrotron Light Research Institute, Nakhon Ratchasima, Thailand
N. Chaijaroenmaitree, K. Phochanasombut
Chulalongkorn University, Bangkok, Thailand

Abstract

Thailand's upcoming 3 GeV light source (SPS-II), based on compact fourth-generation storage ring design, requires precise and reliable operation of pulsed magnet systems for successful beam injection and extraction. The requirements exceed our experience from operations of Thailand's current synchrotron, and also poses significant technical challenge beyond the currently demonstrated capability of local manufacturing. We present our latest progress in developing the pulsed magnets and power supplies domestically.

INTRODUCTION

The Siam Photon Source II (SPS-II), planned for operation in 2034, will be Thailand's new 3 GeV fourth-generation light source based on DTBA (double triple bend achromat) lattice with designed emittance of 0.96 nm · rad [1]. A key goal to the development of Thailand's new synchrotron light source is developing the necessary industrial capabilities to produce at least 50% of all components domestically. Currently, all the vacuum chambers [2] and storage ring magnets [3] are being developed in-house to near completion, satisfying the requirements of a fourth-generation light source. The injection and extraction system poses another set of challenges, as the institutional knowledge to develop and operate pulsed power systems do not currently exist domestically. By self-developing the pulsed magnets and power supplies for SPS-II, we ensure full understanding of the systems and the capability to fix any issues that may arise during commissioning and operation. With the economical savings of self-developed systems compared to turn-key systems, we can also stock replacement parts of the magnets and power supplies, ensuring maximum up-time independent of external parties.

MAGNET DESIGNS

Septum

The storage ring injection septum is the most challenging to design as leak field minimization is crucial in reducing perturbation to the stored beam. The in-air design of the magnet has a maximum allowed septum sheet thickness of 3 mm including the vacuum chambers, due to the small beam offset of 15 mm. Simulations indicate that a 1 mm sheet of copper and a 0.5 mm sheet of NiFe shielding material is enough to minimize the leak field.

Table 1: Key Parameters for the Storage Ring Injection Septum Magnet

Parameters	Septum
Field Strength	0.87 T
Effective Length	1200 mm
Deflecting Angle	6°
Aperture	9 × 20 mm
Beam Offset	15 mm
Septum Thickness	3 mm
Pulse Width	100 µs Half-sine
Current	9 kA
Voltage	2.5 kV

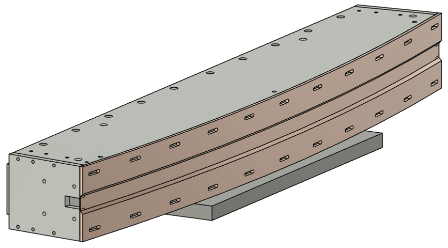

Figure 1: CAD of the prototype septum currently being built. Note that vacuum chambers are not included in the picture.

The septum magnets (booster injection, booster extraction, storage ring injection) are based on the septum of SLS (Swiss Light Source) [4] which has demonstrated reliable operation for over two decades, and the new thick septum of SLS2.0. Figure 1 shows the design, with the structural casing assembled from several pieces of machined 304 stainless steel, with slots for alignment of the silicon steel laminates. The silicon steel laminates are laser-cut with thickness of 0.2 mm, and can be assembled into the structural casing sheet-by-sheet without needing to be bonded together into a solid core. The conductor coil is made from a round copper bar, held in place with fiber-filled composite insulator. The septum sheet is made from a long piece of machined copper, installed onto the magnet after the magnet is positioned onto the prior-installed vacuum chambers at the injection/extraction points. This allows for independent installation and baking of the vacuum systems. The vacuum chamber inside the septum magnet gap is made from seamless 316L stainless steel racetrack tube, with wall thickness of 0.5 mm to minimize field attenuation. The design pa-

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* taylor@slri.or.th

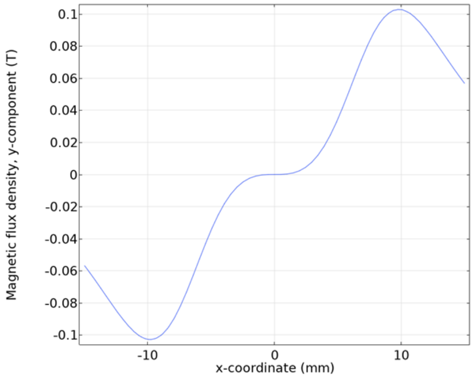

Figure 2: Vertical magnetic field component of the NLK calculated with COMSOL (transient calculation at time of peak current) at the operating current of 3,400 A.

Table 2: Key Parameters for the NLK

Parameters	**NLK**
Field Strength	0.1 T @ 9 mm
Effective Length	400 mm
Deflecting Angle	4 mrad
Aperture	8 × 30 mm
Pulse Width	4 µs Half-sine
Current	3.4 kA
Voltage	6 kV

rameters for the storage ring injection septum is listed in Table 1.

Non-Linear Kicker (NLK)

The SPS-II storage ring injection scheme was designed from the beginning for a non-linear kicker, due to the injection straight section being too short for a traditional four-bump kickers, but with dynamic aperture large enough for efficient off-axis injection. The NLK is based on the magnet developed for BESSY-II [5], now with similar designs also used at MAX-IV [6], SIRIUS [7], and SOLEIL [8]. The design has some advantages over the pulsed quadrupole and pulsed sextupole magnets due to the octupole-like magnetic field which has an extended plateau of the field-free region in the center and zero-crossing at the origin. The high-field area also has low field gradient, enhancing the capture efficiency of the injected beam. The field is shown in Fig. 2.

The NLK is designed based on 8-wire configuration with four inner conductors carrying current in the same direction, while the current in the other four conductors is opposite. The conductors are embedded in a single piece of sintered alumina, shown in Fig. 3. With the peak field position of 9 mm, it is not possible to meet the design requirement if the vertical aperture is set to ±8 mm, equal to the rest of the storage ring. Vertical aperture of ceramic chamber is thus a tradeoff between minimization of stored beam impedance and the operating current of the NLK. Design parameters of the NLK are summarized in Table 2.

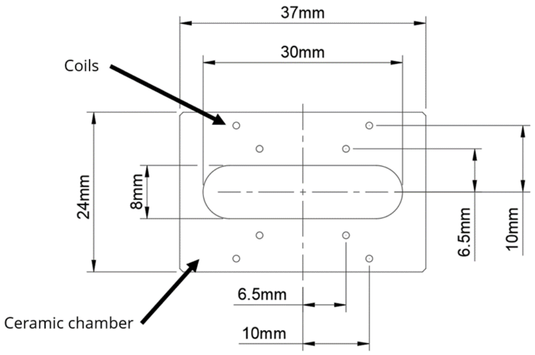

Figure 3: NLK's cross-section with ceramics chamber. Note that the machined grooves for coils installation are not included in the drawing.

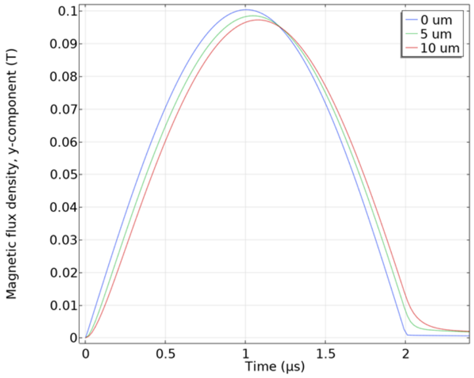

Figure 4: Comparison of different titanium coating thickness. Thicker coating results in more attenuation and time delay of the peak field strength.

The inner surface of the chamber exposed to the stored beam is sputtered with titanium to minimize beam coupling impedance. However, a layer of conductive coating has significant effect on the pulsed field, attenuating the peak field (shown in Fig. 4), and introducing significant time-dependent gradient at the stored beam position due to the eddy current generated in the conductive layer. Unlike dipole fields from misalignment or manufacturing errors, this cannot be easily compensated with additional smaller pulsed magnets. Figure 5 shows the case of a 10 micron thick coating of elemental titanium (assumed conductivity of 2×10^6 S/m). The right plot shows clearly how the multipole field changes with time, changing the direction as the current pulse rises and falls. The maximum value of the resulting gradient around the stored beam position is summarized in Table 3. Based on the storage ring design of SPS-II, the maximum allowable gradient is $\leq 5 \times 10^{-4}$ T/mm at x ±0.2 mm [9], meaning that the maximum coating thickness is only 4 micron.

Due to the high operating current and short pulse width of 2 µs (double the revolution period), the operating voltage of the NLK can reach up to $\sim$12 kV. To lower the operating voltage and simplify the high voltage handling systems, we plan to perform two kicks to the injected bunch instead of one, based on the successful operation of MAX-IV's R1 storage ring [10]. This would double the pulse width to 4 µs, reducing the operating voltage down to $\sim$6 kV, significantly

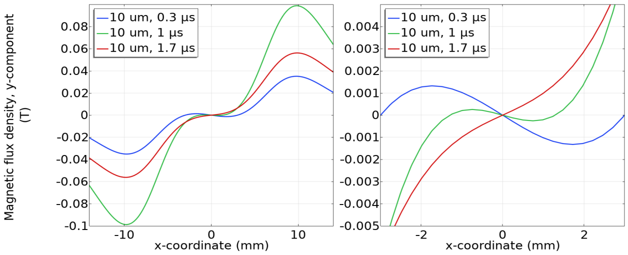

Figure 5: Vertical field of the NLK during current rise (t = 0.3 µs), current peak (t = 1 µs), and current fall (t = 1.7 µs). The right plot is a magnification of the stored beam region of the left plot.

Table 3: Vertical Magnetic Field Gradient Around the Stored Beam Position With Regards to Different Titanium Coating Thickness.

Titanium coating thickness (µm)	**Gradient around stored beam position (± 0.2 mm) (T/mm)**
0	3.1×10^{-5}
5	7.6×10^{-4}
10	1.2×10^{-3}

simplifying the design of all high voltage components. With the longer pulse, the first kick to the injected bunch will occur at the peak of the pulse, and the second kick occurring as the current falls with a kick angle 70% of the first kick. Relying on two kicks for successful injection puts a more rigid constraint on the injection dynamics. However, we have found the most suitable kick combination that gives 100% theoretical injection efficiency without modifying the beam dynamics of the storage ring. As can be seen in Fig. 6, the kicks of the NLK significantly perturbed the shape of the injected bunch causing filamentation, but as SPS-II has not been designed with time-resolved beamlines, this perturbation will not be seen by the users.

PULSED POWER SUPPLIES

The required pulse shape for all pulse magnets are half-sines as SPS-II will operate in only single-bunch mode for both filling and top-up operation. Due to the short pulse width of the kickers and NLK, the switch will be based on IGBTs. The switches for the kickers have been developed in-house, while the switch for the NLK may be procured from BEHLKE if development of higher voltage and current version of the in-house switch is unsuccessful. The switches for the septums will also be developed in-house and based on thyristor switches, with energy recovery for reduced power consumption.

CONCLUSION

An overview of the key design aspects of SPS-II's injection and extraction system have been presented, addressing the stringent requirements of a compact fourth-generation storage ring. The work to develop the pulsed magnet systems for SPS-II is currently in progress, with many components already in production or prototyping stages. A fully operational prototype of a septum magnet and its corresponding pulsed power supply is planned for completion in 2026. In parallel, a prototype of the NLK is under fabrication, with ongoing studies focusing on mitigating the impact of conductive coatings on field quality and optimizing the injection scheme.

Through this work, SPS-II aims to establish domestic expertise in pulsed magnet and high-power pulsed system development. This capability will be essential for long-term operation, maintenance, and future upgrades of the facility, while contributing to the broader goal of strengthening Thailand's high-tech industrial capability.

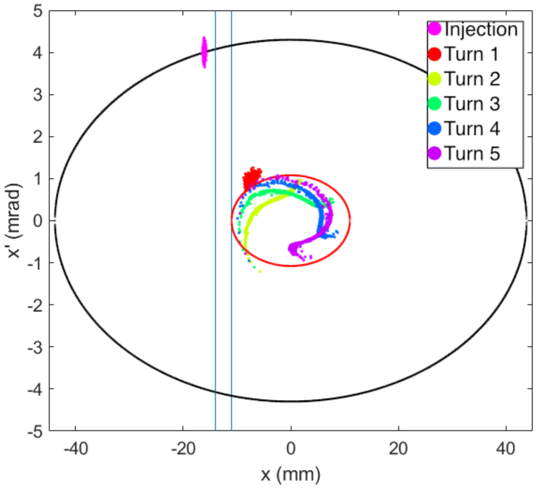

Figure 6: Horizontal phase space of the injected bunch showing the first five turns at the injection point. The injection bunch at the top left is injected from the septum magnet. The turn 1 is the injected bunch after the first kick by the NLK and completion of one turn. After the second kick and completion of the second turn, the turn 2 bunch spreads out in phase space. The red circle denotes the acceptance of the storage ring and the vertical blue lines denote the total septum thickness.

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