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OVERVIEW OF DIAGNOSTIC AND INSTRUMENTATION FOR SIAM PHOTON SOURCE-II

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Abstract

Siam Photon Source II (SPS-II) is a 4th-generation synchrotron light source to be constructed in Thailand, envisioned as a major synchrotron facility for Southeast Asia. It is designed with a 3 GeV low-emittance electron storage ring based on a Double Triple Bend Achromat (DTBA) lattice, with a circumference of 327.6 meters and a natural emittance of 0.97 nm·rad. The design and machine parameters have recently been carefully revised to enhance beam stability and operational reliability. In parallel, key prototypes are being developed to support smooth construction and ensure long-term performance. This paper presents the detailed specifications and a comprehensive overview of the planned beam diagnostics and instrumentation systems, along with initial results from their ongoing R&D and testing.

INTRODUCTION

The SPS-II accelerator complex comprises four main components: a 3.0 GeV low-emittance storage ring, a 0.25–3.0 GeV ramping booster, a 150–270 MeV S-band linac, and low- and high-energy transfer lines [1-3]. The storage ring is based on 14 Double Triple Bend Achromat (DTBA) cells with a natural emittance of 0.97 nm·rad, accommodating insertion devices in both standard and middle straight sections. The linac and booster will operate in single-bunch mode, while the storage ring will run at a high beam current of 300 mA with strict requirements to maintain 1 % beam stability during top-up injection.

To satisfy these demands, a comprehensive diagnostic system has been developed to monitor all major subsystems. It delivers detailed measurements of beam position, intensity, shape, and filling pattern, thereby supporting machine commissioning, beam physics studies, and long-term stable operation.

STORAGE RING DIAGNOSTIC

Beam Position Monitor

A four-button beam position monitor (BPM) was developed to provide high-precision position data in closed-orbit, low to fast feedback, and turn-by-turn modes. The storage ring will employ 140 BPMs, with ten installed per achromatic cell as shown in Fig. 1. Each BPM is designed as a removable flange type, comprising top and bottom flanges mounted on the elliptical chamber [4].

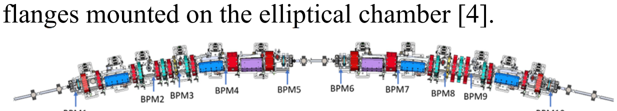

Figure 1: Location of BPMs in the SPS-II storage ring.

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The button geometry, as shown in Fig. 2 was optimized for a resolution of ~100 nm at 100 mA with 2 kHz bandwidth. Each button has a 6 mm diameter, 4 mm thickness, and a 0.3 mm electrode housing gap, chosen to maximize capacitance and shift HOM resonances. A horizontal separation of 10.5 mm yields horizontal and vertical sensitivities of ~0.134. Buttons and central conductors are fabricated from molybdenum and integrated with reverse-polarity SMA connectors, while alumina (Al_2O_3) insulators provide electrical isolation and vacuum sealing.

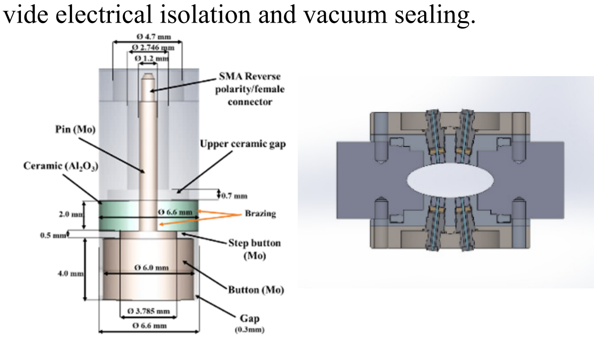

Figure 2: BPM button (left), engineering design of BPM flange installed on the BPM chamber (middle and right).

Current Monitor

The average beam current in the storage ring will be measured using Bergoz's New Parametric Current Transformer (NPCT) [5], which provides a large dynamic range and high bandwidth with a 1 μA/√Hz resolution option. The system consists of a flange-type sensor head, a 19″ 3U RF-shielded chassis with dual power supplies and auto-range AC input, and two NPCT electronic cassettes. The sensors are equipped with radiation-tolerant features and a bake-out option rated for operation below 100 °C.

Beam Loss Monitor

Two complementary systems will be used for beam loss detection and localization. Scintillator–PMT monitors provide fast, localized detection with 8 ns resolution and MHz-level acquisition rates, making them well suited for identifying rapid injection losses. Each unit comprises an EJ-200 scintillator, a Hamamatsu H10721-110 photomultiplier tube, an aluminum housing with lead shielding, and a data acquisition system. In parallel, a fiber-based BLM system using Cherenkov light in long optical fibers will offer simple, cost-effective, distributed detection. Each unit comprises an optical fiber, PMT, and a data acquisition system. The fibers (Thorlabs pure silica, 100 μm core with hard polymer cladding) provide high sensitivity, with about seven 45 m fibers installed around the ring. A prototype has already been set up in the existing machine [6].

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Beam Scraper

A beam scraper system is being developed for SPS-II to define the dynamic aperture, evaluate beam lifetime, and protect insertion devices from large-amplitude particles [7]. Due to lattice space constraints, the scrapers are located in standard straight sections rather than in high-dispersion or high-beta regions. Figure 3 shows the engineering design of the vertical and horizontal scraper chamber. The scraper blades, made of 10 mm-thick CuCr1Zr, were optimized using CST simulations, which demonstrated that a 45° taper with 0.3 mm clearance minimizes wakefield effects. ANSYS thermal analysis under a 100 W load confirmed safe operation with water cooling. The system employs remotely actuated horizontal and vertical blades with micrometer-level positioning accuracy.

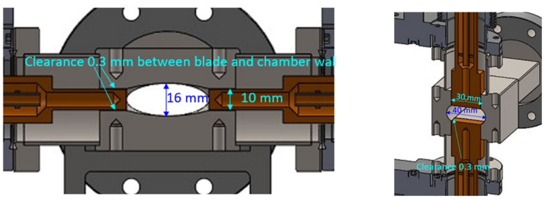


Figure 3: Engineering design of horizontal (left) and vertical (right) beam scraper.

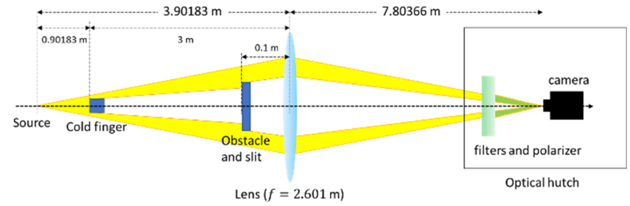
Beam Filling Pattern

A BPM-based system and a time-correlated single photon counting (TCSPC) system will be used to measure and monitor the longitudinal filling pattern. The BPM-based system provides real-time diagnostics by combining diagonal signals from BPM buttons into a SUM signal, digitized at 2 Gs/s. By integrating the pulse areas and scaling them with the DCCT current, absolute bunch currents can be determined. The TCSPC system, installed at the visible light diagnostic beamline, will detect synchrotron radiation with a fast MCP-PMT and a time-to-digital converter (TDC) module. It reconstructs the filling structure with sub-nanosecond resolution and a dynamic range >10^3, enabling highly sensitive analysis of isolated bunches, gaps, and residual charges.

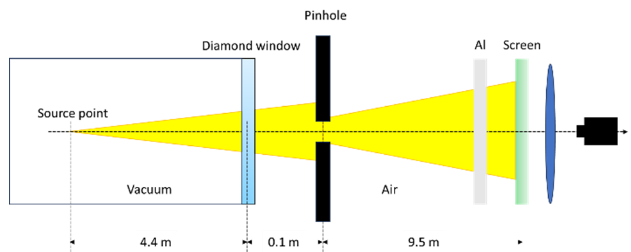
Synchrotron Radiation Monitor

Two synchrotron radiation diagnostics are implemented: a visible-to-ultraviolet (Vis-UV) beamline and an x-ray beamline, both utilizing SR from 0.87 T bending magnets to monitor beam properties across different spectral ranges. The Vis-UV beamline uses vertical polarization to measure transverse beam size with 3 µm resolution and a streak camera for 1 ps bunch length. Key components include a cold finger to absorb hard x-rays, a 2× magnification lens, diffraction obstacles, and a CCD camera setup in the optical hutch. These elements are shown in Fig. 4 (a).

The x-ray pinhole beamline includes a rectangular pinhole, 500 µm diamond window, selectable aluminum filters, and a 30 µm YAG:Ce screen. With the pinhole 4.5 m from the source and the screen 9.5 m downstream, magnification is 2.11. Optimization of pinhole size and filter thickness yielded 19 µm (1 mm Al) and 18 µm (3 mm Al) configurations, giving resolutions of 5.2 µm and 4.8 µm, both well below the expected vertical beam size, ensuring clear images with sufficient photon flux. The layout and configuration are illustrated in Fig. 4 (b).



(a)



(b)

Figure 4: The visible-to-ultraviolet (Vis-UV) beamline (a) and the x-ray beamline (b).

Orbit Feedback System

In the SPS-II storage ring, the minimum vertical beam size is 3.0 µm, occurring in the short straight section. To maintain beam position stability within 10 % of this size (~0.3 µm), two orbit feedback systems are proposed. The slow orbit feedback system addresses DC drift and low-frequency disturbances from ground motion, operating at a few hertz using slow corrector magnets. The fast orbit feedback system compensates for high-frequency orbit perturbations with a 10 kHz sampling rate and ~500 Hz bandwidth. Beam position data from 140 button-type BPMs around the ring will be processed with with data transmitted via fiber optic cables in a daisy-chain configuration using the High-Speed Data Processing and Exchange Module. The corrector magnet includes six slow and four fast horizontal and vertical corrector magnets. Slow correctors are integrated into sextupole coils, while fast correctors are standalone units mounted on a 0.3 mm-thick stainless-steel chamber [8].

Bunch by Bunch Feedback system

To suppress coupled-bunch instabilities, SPS-II will employ a transverse bunch-by-bunch (BBB) feedback system consisting of a button-type BPM, digital controller, broadband amplifier, and in-house–developed stripline kicker. A commercial BBB controller from Dimtel [9] will be used. In the first operation phase, the system will also help control beam emittance, with emphasis on optimizing vertical emittance for improved lifetime.

The stripline kicker comprises two independent units (horizontal and vertical) later assembled into a complete system (Fig. 5). Each unit features 300 mm-long tapered electrodes inside a 68 mm-diameter vacuum chamber, with UHV-compatible Kyocera EIA 7/8" coaxial feedthroughs. The geometry was optimized in 2D/3D to ensure

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impedance matching, maximize kick strength, reduce heating, and minimize transverse coupling impedance. Within the BBB operational range (DC–250 MHz) and 500 W input power, the transverse shunt impedance decreases from ~41.9 kΩ at DC to 20.3 kΩ at at 250 MHz, yielding a beam deflection of 2.16–1.50 µrad per turn [10].

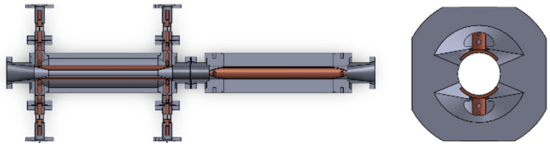

Figure 5: Full mechanical assembly (left) and cross-section (right) of the horizontal and vertical kicker.

BOOSTER DIAGNOSTIC

Screen Monitor

Two screen monitors will be installed downstream of the injection region at the booster entrance. Each monitor combines a YAG:Ce scintillator and an aluminum-foil OTR screen on remotely controlled pneumatic actuators, sharing a common holder. An RF shield suppresses wakefields during normal operation. The optical system includes an LED for illumination, filters, a 45° mirror to deflect light away from the electron beam level, and a bi-convex lens for 1:1 macro focusing. Images are captured by a LAN-connected CMOS CCTV camera. All optical elements are mounted on adjustable rails and enclosed in a removable black acrylic box to block external light. Figure 6 shows Engineering design of screen monitor system and prototype.

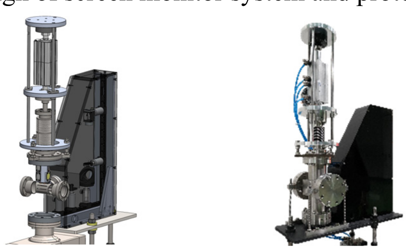

Figure 6: Engineering design of screen monitor system (left) and screen monitor prototype (right).

Beam Position Monitor

In the SPS-II booster synchrotron, each achromatic cell is equipped with five BPMs, for a total of 40 BPMs (Fig. 7). These monitors are crucial for accurate beam position measurements during injection and energy ramping. The booster BPMs adopt a four-button design in a 45° orientation, with a chamber radius of 20.3 mm.

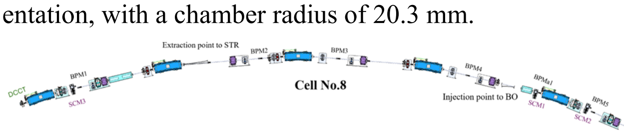

Figure 7: Location of the BPM, screen monitor, DCCT and FCT in the SPS-II booster.

As shown in Fig. 8, each button has a diameter of 14 mm, a thickness of 3.5 mm, and a 0.5 mm gap. The housing is made of Kovar with a stainless-steel flange, while the button head and central conductor are fabricated from molybdenum. A 2 mm alumina (Al_2O_3, 97.6 %) ceramic insulator provides both electrical isolation and vacuum sealing. The optimized design achieves a capacitance of 2.82 pF and position sensitivities of ~0.068. At a beam current of 2 mA, the BPM delivers an intrinsic resolution of 0.13 µm at a 1 kHz bandwidth. The BPM electronics will match those of the storage ring and be software-configurable only (no hardware changes), easing maintenance and enabling use as spares.

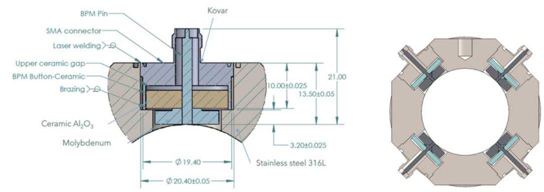

Figure 8: The BPM button geometry and engineering design of BPM in the SPS-II booster

Current Monitor

The beam current in the booster will be measured using a Bergoz NPCT. A flange-type model with a 1 µA/√Hz resolution option and a custom 40.6 mm inner diameter has been selected to match the booster's round vacuum chamber.

TRANSFER LIN DIAGNOSTIC

Integrated current transformers (ICTs) will be installed at the entrance and exit of the LBT and HBT to measure the current in single-bunch operation and transmission efficiency. Bergoz in-flange ICTs (DN/NW63CF, 40 mm axial length) customized with an inner diameter matching the LBT and HBT vacuum chambers will be used. Each ICT will be connected via coaxial cable to a fast digitizer (2 GS/s) and monitored in the control room. Six BPMs in the LBT and four BPMs in the HBT will provide beam position measurements. To simplify the design, the BPMs adopt the same button geometry as in the booster. The BPM processing module uses a single-pass algorithm to calculate the beam position as it propagates through the transfer line. Additionally, three screen monitors will be installed in both the LBT and HBT for beam size and emittance measurements. Each monitor integrates YAG:Ce and OTR screens of the same design as those in the booster. An energy slit, 150 mm in length, will be placed at the high-dispersion location in the achromat to filter out low-energy particles.

CONCLUSION

Beam diagnostics for SPS-II have been designed to meet the stringent requirements of a 4th-generation synchrotron light source. The systems address beam stability, current measurement, loss detection, and filling pattern control, ensuring reliable operation at high current with top-up injection in single-bunch mode. Prototypes of key components, including BPMs, scrapers, and stripline kickers, are being developed to verify the design and validate performance ahead of installation, supporting smooth commissioning and long-term stable operation of SPS-II as a major synchrotron facility for Southeast Asia.

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