

ALIGNMENT NETWORK DESIGN FOR THE SIAM PHOTON SOURCE II

J. Saetiaiw[†], S. Prawanta, P. Kulnok, K. Rittaprom, P. Pruekthaisong, S. Srichan, P. Klysubun
Synchrotron Light Research Institute, Nakhon Ratchasima, Thailand

Abstract

The Siam Photon Source II (SPS-II) is Thailand's next-generation 3 GeV synchrotron light source, currently undergoing detailed design and preparation for the construction of the accelerator facility. The facility comprises a 270 MeV linear accelerator, a 3 GeV booster synchrotron, a 3 GeV storage ring designed to achieve an electron beam emittance of less than 1 nm·rad, and beamlines.

A robust alignment network is essential for achieving high-precision component installation, accurate verification, long-term positional stability, and reliable future realignment.

This paper presents the design of the SPS-II alignment network developed to support the installation, alignment, and maintenance of the accelerator complex. The proposed system comprises a three-level hierarchical reference network: the Ground Control Network, the Primary Network, and the Alignment Network. These networks are established using floor and wall monuments distributed throughout the accelerator tunnels and experimental areas to achieve the required positioning accuracy of ± 0.1 mm.

A laser tracker system is employed as the primary instrument for high-precision three-dimensional measurements of the alignment network. The measurement data are subsequently processed, and the network is adjusted using the Unified Spatial Metrology Network (USMN) algorithm implemented in Spatial Analyzer (SA) software. This integrated measurement and adjustment approach enables the establishment of a consistent, accurate, and reliable three-dimensional coordinate reference system.

The proposed network supports the installation process, including pedestal positioning and installation, girder-magnet assembly installation, alignment, and periodic verification of component positions. In addition, the network serves as a reference frame for integrating survey data throughout the installation, commissioning, operation, and

future maintenance phases, enabling the synchrotron light source to maintain the required positioning accuracy and long-term operational stability. [1]

INTRODUCTION

The Siam Photon Source II (SPS-II) is Thailand's next-generation 3 GeV synchrotron light source, currently undergoing detailed design and preparation for the construction of the accelerator facility (see Fig. 1). The facility comprises a 270 MeV linear accelerator, a 3 GeV booster synchrotron, a 3 GeV storage ring designed to achieve an electron beam emittance of less than 1 nm·rad, and beamlines (see Fig. 2).

The 327.6 m circumference storage ring comprises 14 Double Triple-Bend Achromat (DTBA) cells, with various accelerator components distributed throughout the ring. The installation of these components requires high positional and angular accuracy to ensure proper electron beam confinement and trajectory control. Even small deviations may affect electron beam dynamics and, consequently, the stability of synchrotron light production. Therefore, accurate and consistent positioning of the accelerator components throughout the installation process is critical [2,3].

Installing accelerator components with the required high positional accuracy requires a stable and consistent reference framework to ensure the reliable transfer of spatial coordinates between measurement locations. Errors introduced during individual alignment stages may propagate through the reference system and accumulate, resulting in deviations of component positions from their intended locations. Therefore, a systematic approach to establishing a coordinate reference network, coordinate control, and verification is essential to minimize error propagation and maintain the required alignment accuracy throughout the accelerator complex.



Figure 1: Overview of the Siam Photon Source II facility.

[†] jullada@slri.or.th

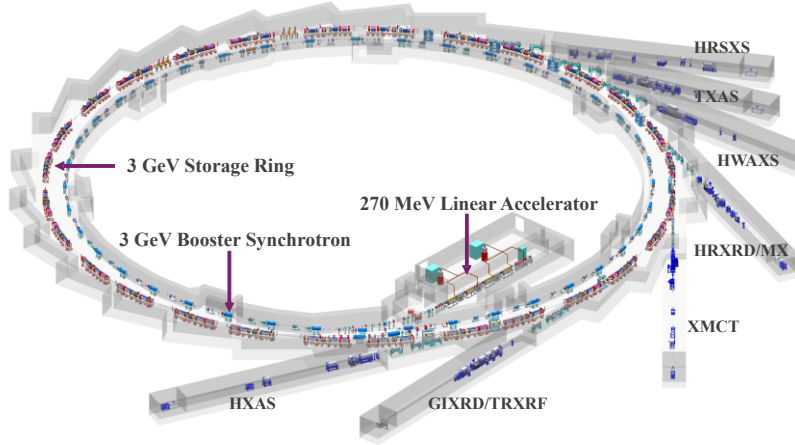


Figure 2: Overview of the SPS-II accelerators complex.

ALIGNMENT NETWORK DESIGN

The SPS-II spatial reference system is established as a three-level hierarchical network comprising the Ground Control Network (± 3 mm horizontal, ± 2 mm vertical), the Primary Network (± 1 mm horizontal, ± 0.1 mm vertical), and the Alignment Network. As the highest-precision level, the Alignment Network directly supports component installation and alignment, with a required positioning accuracy of ± 0.1 mm in both horizontal and vertical directions (see Fig. 3). It consists of permanently installed floor and wall monuments that provide a common three-dimensional reference framework for coordinate transfer during installation, alignment, verification, and future realignment.

The network geometry was designed by considering station configuration, point spacing, visibility, connectivity, and measurement redundancy. Common points between adjacent stations maintain coordinate consistency and provide sufficient redundancy for uncertainty evaluation. These design parameters were subsequently investigated through uncertainty simulations and field measurements using a Laser Tracker and the USMN method.

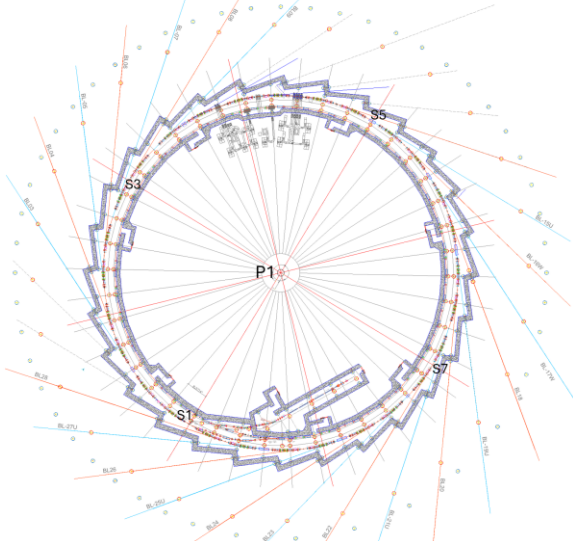


Figure 3: The layout of alignment network design.

UNCERTAINTY SIMULATION

Assessing the uncertainty of the alignment network is a critical step in determining whether the designed network can satisfy the specified accuracy requirements. The simulation was performed using a three-dimensional measurement model of the network, considering uncertainties associated with the instrument's distance and angular measurements, as well as the measurement connections between survey stations and reference points. The simulation results were used to evaluate the coordinate uncertainty of individual points and to assess the robustness of the network prior to field implementation. [4-6]

SA/USMN Methodology

The network analysis was performed using Spatial Analyzer (SA) with the Unified Spatial Metrology Network (USMN) module for network adjustment and coordinate uncertainty evaluation. Measurement data from the Laser Tracker stations and reference points were incorporated into the network model and processed using a Weighted Least-Squares adjustment to determine the most consistent coordinates of all points while accounting for the constraints and measurement uncertainties associated with each observation type. This approach enables the assessment of the effects of network geometry and measurement redundancy on the positional accuracy of the network.

Simulation Setup

A simulation model was developed for the proposed alignment network of the full SPS-II storage ring (approximately 327.6 m in circumference), with Laser Tracker stations and reference points representing the actual installation environment. Four station configurations (Table 1) were compared to identifying a suitable field implementation strategy. Stations were arranged sequentially with overlapping common points, incorporating instrument uncertainties, observation geometry, point connectivity, and line-of-sight constraints to represent actual survey condition.

Simulated Results

The simulation results demonstrate the level of three-dimensional coordinate uncertainty resulting from different measurement-station configurations and reference-station constraints. Network geometry, station distribution, and point connectivity directly influence network strength, with increased redundancy improving stability and reducing uncertainty. The results are summarized in Table 1

Table 1: Simulation Results Uncertainty for Alignment Network

Case	Fix Station	Umag (Max)
1	Free station	0.1526
2	Station Fix: S1	0.9228
3	Station Fix: P1	0.3920
4	Station Fix: S1, S3, S5, S7	0.0905

As shown in Table 1, with each reference point observed from four station positions to provide sufficient measurement redundancy, Case 1 (Free Station) resulted in a maximum uncertainty of 0.1526 mm, while Case 2 and Case 3, with only one constrained reference station, resulted in higher uncertainties of 0.9228 mm and 0.3920 mm, respectively. In contrast, Case 4, with four constrained reference

stations, achieved the lowest uncertainty at 0.0904 mm, satisfying the ± 0.1 mm requirement. Although Case 4 provided the best simulated performance, it relies on the continuous positional stability of four constrained reference stations; if any were disturbed by construction activity, thermal effects, or ground settlement, the resulting error would propagate directly into the network as a systematic bias. In contrast, Case 1 performs a free-network adjustment with no externally fixed points, distributing residuals across the whole network and making it inherently more robust to localized point instability, even though its uncertainty (0.1526 mm) marginally exceeds the ± 0.1 mm target. Considering both robustness and practical feasibility—and since the initial validation was limited to a DTBA cell prototype, making a full-ring constrained configuration (Case 3 or 4) impractical at this stage—Case 1 was adopted as the baseline for methodology validation, with network refinement planned for full-scale implementation. The simulation results, as shown in Fig.4, were subsequently used as a basis for planning the field measurement strategy and evaluating the performance of the pro-posed Alignment Network under realistic measurement conditions. The field measurements were then performed using the same network configuration to further assess network repeatability and coordinate uncertainty.

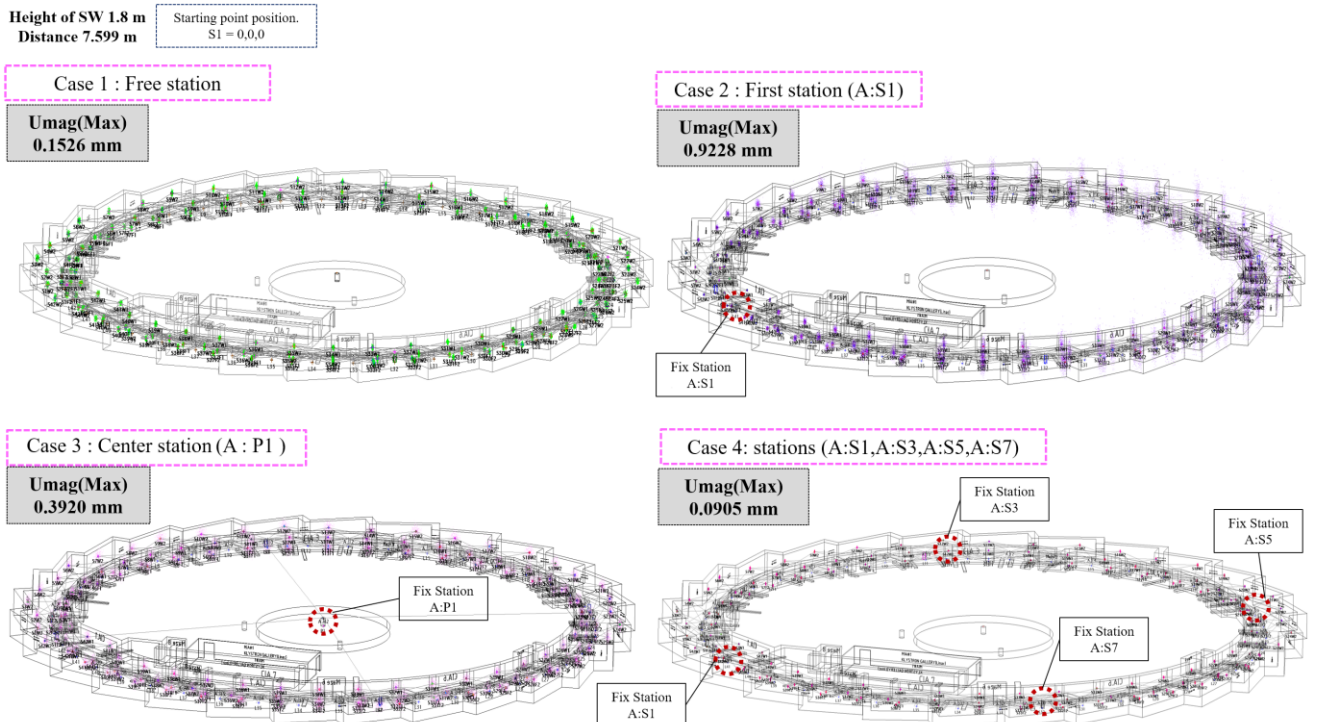


Figure 4: Simulated uncertainty of the alignment network.

PROTOTYPE AND FIELD MEASUREMENT

Based on the simulation results, which demonstrated that the measurement-station configuration has a significant influence on the uncertainty of the Alignment Network, a DTBA cell prototype was constructed, and field measurements were performed to evaluate the suitability of the proposed network under realistic operating conditions. The test covered the prototype setup, Laser Tracker instrumentation, measurement procedure, and data pro-cessing from multiple measurement station.

DTBA Cell Prototype Setup

A DTBA cell prototype was constructed in the Pilot Plant Building at the Synchrotron Light Research Institute (SLRI) to replicate the physical characteristics and key layout features of the accelerator installation area. The

prototype included Alignment Network reference points installed on the floor and walls, as well as designated locations for accelerator components such as girders and magnets, providing a measurement environment representative of the actual installation conditions. The reference-point layout and measurement-station positions were defined according to the configuration used in the simulation, allowing the simulation results to be directly compared with the field-measurement results.

The prototype was used to evaluate the network establishment procedure, measurement-station positioning, and connectivity between reference points, as well as to assess practical constraints such as available space and line-of-sight during field operations (see Fig.5). The test also provided an opportunity to verify the measurement workflow and identify potential limitations that may require improvement before applying the methodology to the full-scale SPS-II Alignment Network (see Fig.6).



Figure 5: DTBA cell prototype and laser tracker setup in the pilot plant.

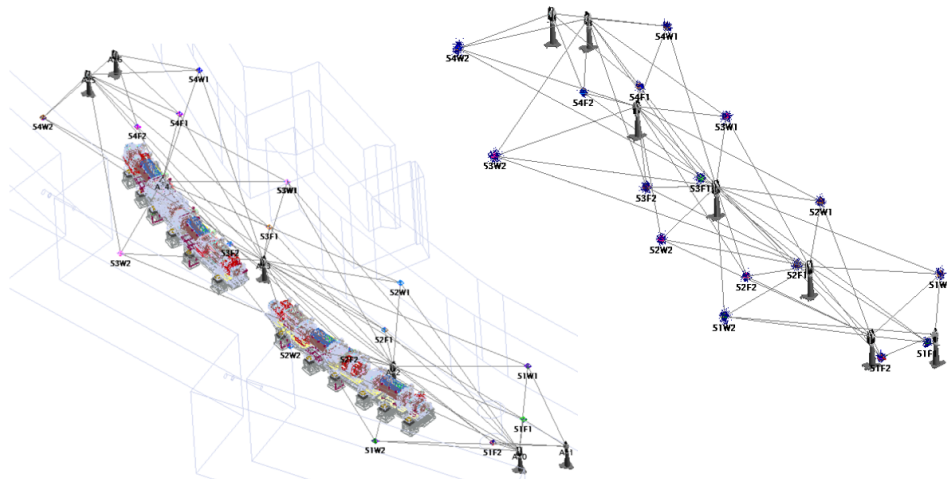


Figure 6: Measurement station configuration and reference point connectivity in the DTBA cell prototype.

Instrumentation (Laser tracker AT500)

Three-dimensional coordinates of the reference points were measured using a Leica Laser Tracker AT500 as the primary measurement instrument, with manufacturer-specified accuracies of $\pm (15 \mu\text{m} + 6 \mu\text{m/m})$ for distance and $\pm 23 \mu\text{m}$ for angular. These instrument uncertainties were used as input parameters for the network simulation described in the following section. The measurement-station positions were selected according to the configuration used in the simulation, taking into consideration the working range, available space for instrument setup, and line-of-sight to the reference points. Common points visible from adjacent measurement stations were used to connect the network observations, allowing measurements from multiple stations to be combined into a common coordinate system and providing measurement redundancy.

Measurement Procedure

The Laser Tracker was set up sequentially at each designated station, with line-of-sight and site conditions verified beforehand. At each station, reference points within the field of view were measured, with particular emphasis on common points shared with adjacent stations to establish network connectivity. This process continued until all reference points in the DTBA cell prototype were covered, replicating the intended SPS-II measurement workflow.

Data processing

The measurement data acquired using the Laser Tracker AT500 were imported into Spatial Analyzer (SA) and processed using the Unified Spatial Metrology Network (USMN) function to combine observations from multiple stations and perform network adjustment. To evaluate the repeatability and stability of the Alignment Network, the same measurement procedure was repeated at three different time periods under the same network configuration. The results were evaluated in terms of Overall RMS, Average Point Error, Maximum Point Error, Average Uncertainty Magnitude, and Maximum Uncertainty Magnitude, as summarized in Table 2.

Table 2: Summary of Repeated Field-Measurement Results at Three Time Periods

Parameter (mm)	Meas. 1 (mm)	Meas. 2 (mm)	Meas. 3 (mm)
Overall RMS	0.0968	0.1090	0.1017
Average Point Error	0.0571	0.0675	0.0621
Maximum Point Error	0.4049	0.5160	0.4714
Average Uncertainty Magnitude	0.0188	0.0191	0.0175
Maximum Uncertainty Magnitude	0.0251	0.0261	0.0233

Overall RMS and point error (Table 2) varied moderately across the three sessions but remained comparable, indicating consistent measurement performance.

Uncertainty magnitude likewise varied only slightly between sessions, demonstrating good repeatability, with all maximum values well below the $\pm 0.1 \text{ mm}$ requirement.

The repeated measurements at different time periods provide an assessment of the repeatability and temporal stability of the proposed Alignment Network. The consistency of the uncertainty results demonstrates that the network can provide a stable three-dimensional reference framework under the tested conditions. These field-measurement results were subsequently compared with the simulation results to evaluate the agreement between the predicted and experimentally obtained network performance.

COMPARISON OF SIMULATED AND MEASURED RESULTS

To evaluate the performance of the proposed Alignment Network at the scale validated in the field, a separate simulation was performed specifically for the DTBA cell prototype geometry, distinct from the full-ring simulation presented in Table 1. This prototype-scale simulation was carried out in Spatial Analyzer (SA) using the Unified Spatial Metrology Network (USMN) function, under the Free Station configuration (Case 1) and the same reference-point layout, station positions, and measurement connectivity as the physical DTBA cell prototype. The results were then compared with three independent field-measurement trials to assess the agreement between predicted and experimentally obtained network performance. The comparison focused on the Overall RMS, Average Point Error, Maximum Point Error, Average Uncertainty Magnitude, and Maximum Uncertainty Magnitude, as summarized in Table 3.

Table 3: Comparison of Simulation and Field-Measurement Results for the DTBA Cell Prototype

Parameter (mm)	Simulation	Meas.1 (mm)	Meas.2 (mm)	Meas.3 (mm)
Overall RMS	0.0262	0.0968	0.1090	0.1017
Average Point Error	0.0171	0.0571	0.0675	0.0621
Maximum Point Error	0.1093	0.4049	0.5160	0.4714
Average Uncertainty Magnitude	0.0260	0.0188	0.0191	0.0175
Maximum Uncertainty Magnitude	0.0332	0.0251	0.0261	0.0233

The lower simulated uncertainty in Table 3 (0.0332 mm) compared with the full-ring Case 1 result in Table 1 (0.1526 mm) reflects the smaller spatial extent and denser connectivity of the DTBA cell prototype; these results therefore validate the measurement methodology rather than directly represent the full-scale network's expected uncertainty. As Table 3 shows, field RMS and point error consistently exceeded the simulated values — attributable to practical effects (instrument setup, environmental conditions, target positioning) not captured in the idealized model.

Uncertainty magnitude, however, was consistently lower in the field than simulated, showing the simulation provides a conservative estimate under the tested conditions.

Notably, the larger field point errors did not translate into proportionally larger coordinate uncertainty — isolated measurement residuals reflect local conditions rather than overall network uncertainty.

Overall, the comparison demonstrates that the simulation successfully captures the general uncertainty behavior of the proposed Alignment Network, while the field measurements provide additional information on practical effects that are difficult to represent in the idealized model. The consistency of the uncertainty magnitudes across the three measurement trials supports the suitability of the proposed network configuration for the DTBA cell prototype and provides a basis for further validation and refinement before full-scale implementation of the SPS-II Alignment Network.

CONCLUSION

The SPS-II Alignment Network has been developed as a three-level hierarchical reference framework to support high-precision installation, alignment, verification, and long-term maintenance of the accelerator complex. The proposed approach integrates a Laser Tracker system for high-precision three-dimensional measurements with the Unified Spatial Metrology Network (USMN) algorithm implemented in Spatial Analyzer (SA) for network adjustment and uncertainty evaluation.

Network simulations demonstrated that the measurement-station configuration and reference-station constraints have a significant influence on the resulting network uncertainty. The four-station constrained configuration achieved a maximum uncertainty magnitude of 0.091 mm, satisfying the required positioning accuracy of ± 0.1 mm. For field implementation, the Free Station configuration was selected because it provides greater flexibility in adapting measurement-station locations to site conditions and line-of-sight constraints.

The DTBA cell prototype validation demonstrated the repeatability and stability of the proposed measurement and network adjustment approach. Three independent measurement sessions yielded maximum uncertainty magnitudes of 0.025, 0.026, and 0.023 mm, respectively, all of

which were substantially below the specified tolerance and showed strong consistency across the three sessions. These results demonstrate the consistency of the measurement results and the stability of the network under repeated measurements.

These results demonstrate that the proposed Alignment Network provides a stable and reliable three-dimensional coordinate reference framework for high-precision accelerator installation and alignment. Future work will extend the network to larger sections of the accelerator complex and investigate the effects of temperature variation and structural vibration on long-term network stability and positioning accuracy.

ACKNOWLEDGEMENTS

The authors would like to express their gratitude to the Synchrotron Light Research Institute (SLRI) for its support and provision of resources.

REFERENCES

- [1] F.Q. Wei et al., “Survey and alignment for the Swiss Light Source,” in Proc. IWAA’99, Grenoble, France, 1999.
- [2] W. Y. Lai *et al.*, “Alignment design and status of Tai-wan Photon Source,” in Proc. *IPAC’15*, Richmond, VA, USA, May 2015, pp. 3212-3214.
[doi: 10.18429/JACoW-IPAC2015-WEPHA044](https://doi.org/10.18429/JACoW-IPAC2015-WEPHA044)
- [3] H. Geraissate, G. Rovigatti, and R. Leão, “Establish-ing a metrological reference network for the alignment of Sirius,” in Proc. *IPAC’21*, Campinas, Brazil, May 2021, pp.2214-2217.
[doi: 10.18429/JACoW-IPAC2021-TUPAB310](https://doi.org/10.18429/JACoW-IPAC2021-TUPAB310)
- [4] R.J. Leão, “Uncertainty evaluation for the alignment of particle accelerators: Application to the Brazilian synchrotron light source Sirius,” Ph.D. dissertation, Instituto Tecnológico de Aeronáutica, São José dos Campos, Brazil, 2017.
- [5] R.J. Leão et al., “Engineering survey planning for the alignment of a particle accelerator: part II. Design of a reference network and measurement strategy,” *Meas. Sci. Technol.*, vol. 29, no. 3, p. 034007, 2018.
[doi: 10.1088/1361-6501/aa9dc3](https://doi.org/10.1088/1361-6501/aa9dc3)
- [6] J.M. Calkins, “Quantifying coordinate uncertainty fields in coupled spatial measurement systems,” Ph.D. dissertation, Virginia Polytechnic Institute and State University, Blacks-burg, VA, USA, 2002