

Improvement of Magnetic Field Measurement for the Storage Ring Magnets of Siam Photon Source II

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Abstract

Prototypes of storage ring magnets for the Siam Photon Source II (SPS-II), Thailand's next-generation 3 GeV synchrotron light source, have been successfully developed. The prototype magnets achieved a pole profile accuracy within 20 μm and an assembly accuracy better than 40 μm . The original magnet alignment was performed using mechanical adjustment. Initial magnetic field characterization using a stretched-wire measurement system demonstrated a normalized multipole measurement repeatability within $1\text{E-}4$. In this work, the magnetic field measurement and alignment procedures have been significantly improved through the commissioning of a high-precision measurement facility, enhanced temperature control, improved magnet support design, and the introduction of high-precision grooves for magnet alignment. Magnet dimensional inspection and magnetic field measurements have been performed under these improved conditions. The measurement setup and alignment strategy will be presented, together with an updated evaluation of magnetic performance, and overall alignment precision for the SPS-II storage ring magnets.

INTRODUCTION

A prototype storage-ring magnet for Thailand's next-generation light source, Siam Photon Source II (SPS-II), has been successfully developed by the Synchrotron Light Research Institute (SLRI). The prototype magnet was precisely fabricated with a pole-profile accuracy better than 20 μm and an assembly accuracy better than 40 μm . The magnetic field of the prototype magnet was characterized using an in-house developed stretched-wire measurement system [1]. The system demonstrated a normalized multipole measurement repeatability better than 1×10^{-4} . It was designed to accommodate a maximum wire displacement of ± 100 mm in both the horizontal and vertical directions, with a positioning accuracy of ± 2 μm . The measurement system is installed on a 3.2 m long precision granite support, allowing the characterization of magnets up to 2.2 m in length and weighing up to 2,500 kg. The optimal operating parameters of the system were investigated and listed in Table 1.

IMPROVEMENT OF STRETCHED WIRE MEASUREMENT SYSTEM

Main limitation of the previous stretched-wire measurement system was the lack of a sufficiently precise instrument for determining the positions of both the

magnet and the wire. To address this issue, a mid-size bridge-type Coordinate Measuring Machine (CMM) made by LK Metrology [2] with a large working volume was employed. The CMM provides high measurement accuracy, with an error of $1.4 \mu\text{m} + L/375 \mu\text{m}$, where L is the measured length in millimetres. The previous stretched-wire measurement system was relocated from the granite support to the CMM workbench, as shown in Fig. 1. A precision grinded stainless-steel plate was used as a dummy girder for mounting the magnet on the CMM. The dummy girder was equipped with a centre bar having a controlled straightness of better than 20 μm , which served as the vertical reference surface of the girder. The wire length was measured using the CMM and was determined to be 1,131 mm. The CMM was installed in a temperature-controlled room, and the ambient temperature was continuously monitored throughout the measurement process.

Table 1 Parameters of the stretched wire measurement system of SLRI

Parameters	Value
Wire	Copper Beryllium (CuBe)
Wire diameter	0.2 mm
Wire tension	1,400 g
Scan region	± 1 mm
Pause time	1 sec
Wire speed	20 mm/s

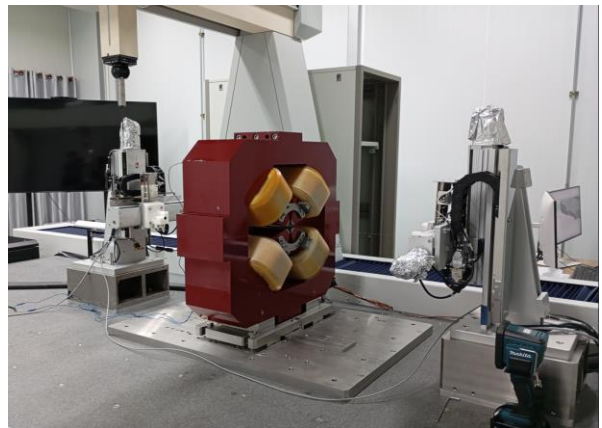


Figure 1: Relocated stretched-wire measurement system installed on the CMM workbench.

MECHANISM FOR MAGNET ALIGNMENT

Magnet support

The magnet support was designed to both secure the magnets to the girder and enable precise adjustment of the magnet position and orientation for alignment purposes. The support made from a 35 mm thick stainless steel base plate. Four Shims Y are used to support the magnet weight and to adjust the vertical position, pitch angle, and roll angle. Two Shims X are provided for lateral position and yaw angle adjustment. The longitudinal position of the support is controlled by a locating pin, the final location of which is determined after the magnet has been aligned. The support is fastened to the girder using four M16 bolts. In addition, one side of the base plate is locked with a taper block to ensure that the magnet support is firmly pushed against the vertical reference plane.

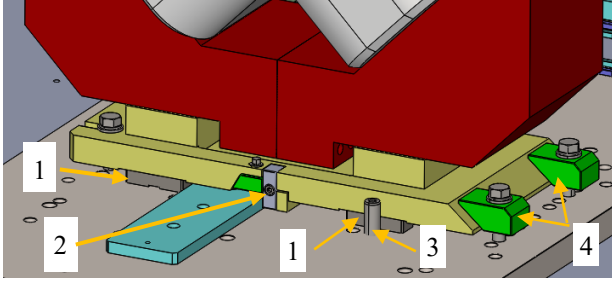


Figure 2: Magnet support assembly for the quadrupole magnet, equipped with (1) Shim Y, (2) Shim X, (3) longitudinal pin, and (4) taper lock block, shown from the upstream side.

Wire position

The wire position can be measured from the vertical and horizontal reference planes of the wire holder, see Fig. 3. Both ends of wire position were adjusted to coincide with the mechanical center axis of the magnet. This position was then used as the initial reference for the magnetic field measurement.

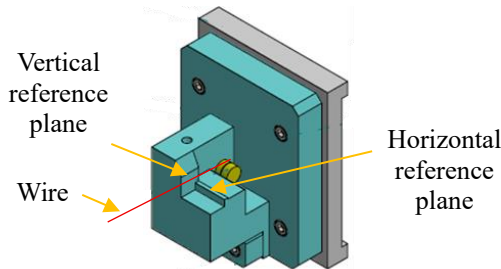


Figure 3: Wire holder of the stretched-wire measurement system.

Mechanical center of magnet

The mechanical center of the magnet was determined using the pole reference surfaces in the horizontal, vertical, and longitudinal directions, as shown in Fig. 4. A series of points on each reference surface were measured

with the CMM, and best-fit middle planes were calculated from the acquired data. The mechanical center point was subsequently defined as the intersection of the horizontal, vertical, and longitudinal middle planes.

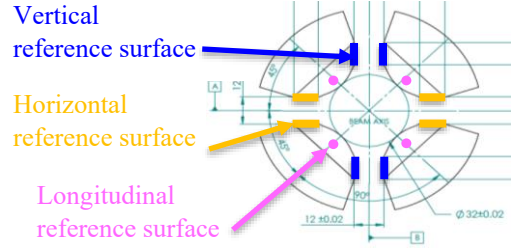


Figure 4: Pole reference surfaces of the quadrupole magnet.

Magnetic center of magnet

The magnetic center of the magnet was measured using the stretched-wire measurement system [3]. This system is based on Faraday's law of electromagnetic induction, whereby an electromotive force is induced in a conducting wire when it moves through a magnetic field. As the wire is displaced, the induced voltage is integrated to obtain the magnetic flux. If d is the displacement of the wire, Φ is the measured magnetic flux, and x_0 and y_0 are the initial wire positions which were aligned to the mechanical center axis of the magnet. The magnetic center position x_c , y_c can be determined from the variation of the measured magnetic flux with respect to the wire position, as given by

$$x_c = x_0 - \frac{d}{2} \frac{\Phi(x_0, x_0 + d) - \Phi(x_0, x_0 - d)}{\Phi(x_0, x_0 + d) + \Phi(x_0, x_0 - d)} \quad (1)$$

$$y_c = y_0 - \frac{d}{2} \frac{\Phi(y_0, y_0 + d) - \Phi(y_0, y_0 - d)}{\Phi(y_0, y_0 + d) + \Phi(y_0, y_0 - d)}$$

MAGNET ALIGNMENT STRATEGY

The magnet with support was initially mechanically pre-aligned by the manufacturer. Nevertheless, its position and orientation were re-evaluated using the CMM and the stretched-wire measurement system and fine-adjusted to achieve the specified alignment tolerances and target coordinates.

Coordinate system

A new U-V-W coordinate system was established for magnet alignment. Its origin is located on the vertical reference plane and 15 mm above the dummy girder flat surface, as shown in Fig. 5. However, the coordinates obtained from the CMM are expressed in the CMM coordinate system denoted as X_{CMM} - Y_{CMM} - Z_{CMM} . In addition, the X-Y-Z coordinate system is used to represent the local coordinate system of an individual magnet, with its origin defined at the mechanical center of the magnet.

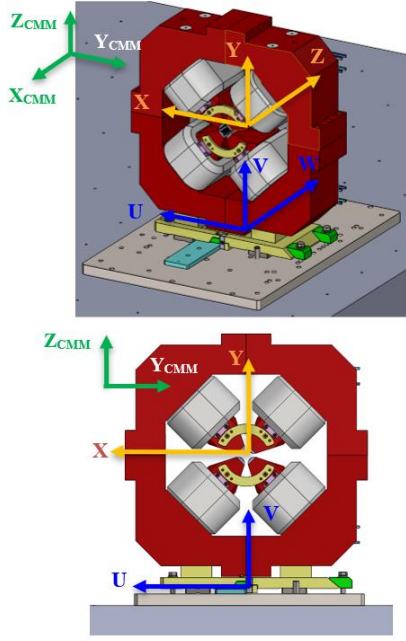


Figure 5: Coordinates of the magnet for alignment in the U-V-W, local X-Y-Z and CMM X_{CMM} - Y_{CMM} - Z_{CMM} coordinate systems.

Alignment of Magnet Position

The magnet position was aligned by comparing the magnetic center position measured using the stretched wire system with the target position. The target magnetic center position in the U-V-W coordinate system was defined as (0, 430, 0) mm. The positioning error must be within 30 μ m in U and V direction and 200 μ m in the W direction. Based on the measured deviation from the target coordinates, alignment corrections were applied and the magnet was repositioned until the required alignment tolerances were achieved.

Alignment of Magnet Orientation

The magnet orientation about the U, V, and W axes, referred to as the pitch, yaw, and roll angles, respectively, was aligned using different strategies. The pitch and yaw angles were aligned based on the mechanical center axis of the magnet because the current stretched-wire measurement system is unable to directly measure the angular orientation of the magnetic field. In contrast, the roll angle was determined by evaluating the dependence of the magnetic center position in the U direction on the V position. The orientation error was required to be less than 200 μ rad.

MEASUREMENT RESULT

The prototype quadrupole magnet was used to evaluate the performance of the new measurement system setup. The magnet was designed for the SPS-II storage ring, with a field gradient of 45 T/m, operating current of

85 A and an effective length of 215 mm. The measurement parameters were identical to those used in the previous setup and are listed in Table 1. The applied current was limited to 40 A because no cooling system was available for the magnet coils during the measurements. The ambient temperature in the CMM room was monitored during the measurements. The average temperature was 22.32 $^{\circ}$ C with a standard deviation of 0.21 $^{\circ}$ C. The recorded temperature variation is shown in Fig. 6.

The coordinates of the U-V-W origin were established by measuring the flat surface of the dummy girder and the vertical surface of the center bar, with the results summarized in Table 2. The magnetic center was subsequently determined as a displacement relative to the mechanical center, with the reported values representing the average of three measurements performed over a displacement range of ± 1 mm. The measured mechanical center position, the magnetic center position, and the misalignment angles are presented in Table 3 and Table 4, while the calculated thickness adjustments for the shims are provided in Table 5. The analysis indicates that the shim Y required modification, specifically a thickness reduction of approximately 0.3 mm. As shown in Fig. 7, the magnetic center position in the U direction remained nearly constant at approximately 0.025 mm as the V position was varied, indicating the absence of significant roll misalignment.

Table 2: CMM-measured coordinates of the U-V-W origin

Items	X_{CMM}	Y_{CMM}	Z_{CMM}
- CMM Coordinate of U-V-W origin	1805.707	1452.226	-1193.648

Table 3: Measurement results of the mechanical and the magnetic center of the quadrupole magnet.

Items	U	V	W
	[mm]	[mm]	[mm]
- Target coordinates of the magnetic center	0	430	0
- Mechanical center offset from the target coordinates	-0.028	0.204	0
- Magnetic center offset from the mechanical center	0.025	0.103	0
- Calculated magnetic center offset from the target coordinates	-0.003	0.307	0

Table 4: Measurement results of the mis-alignment angle.

Items	Pitch	Yaw	Roll
	[μ rad]	[μ rad]	[μ rad]
Mis-alignment angle	63.13	53.33	0

Table 5: Required shim thickness adjustments for magnet alignment.

Shim	Upstream [mm]	Downstream [mm]
Shim Y	-0.315	-0.3
Shim X	-0.009	0.003

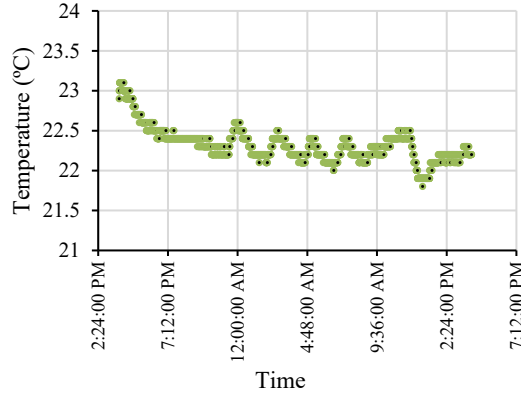


Figure 6: Ambient temperature recorded in the CMM room during the measurement period.

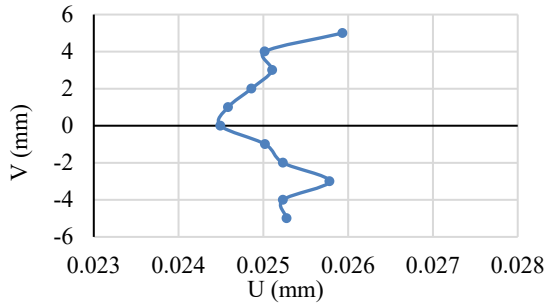


Figure 7: Measured magnetic center position offset from the mechanical center in the U direction.

CONCLUSION

The new set up of the stretched-wire measurement system installed on the CMM workbench provides high-precision mechanical measurements, resulting in improved accuracy of the magnetic center determination. The integration of the stretched-wire system with the CMM enables precise positioning and alignment of the wire and magnet, reducing uncertainties associated with previous setups. However, the measured offset between the magnetic center and the mechanical center was relatively large, reaching 0.103 mm. This discrepancy may be attributed to several factors, including limitations in the accuracy of the wire holder reference surfaces, the influence of background magnetic fields, wire sag or measurement uncertainties within the system. Further investigation is required to identify the dominant sources

of error and to improve the overall accuracy of the measurement system.

REFERENCES

- [1] P. Sunwong *et al.*, “Development of stretched wire system for magnetic field measurement of magnets for Siam Photon Source II,” in *Proc. 16th Int. Particle Accelerator Conf. (IPAC'25)*, Taipei, Taiwan, Jun. 2025, Paper WEPS049, doi: 10.18429/JACoW-IPAC2025-WEPS049.
- [2] LK metrology website
<https://www.lkmetrology.com/>
- [3] P. Arpaia *et al.*, “Performance of the Stretched- and Vibrating-Wire Techniques and Correction of Background Fields in Locating Quadrupole Magnetic Axes,” in *Proceedings of the XXI IMEKO World Congress: Measurement in Research and Industry*, Prague, Czech Republic, Aug. 30 to Sep. 4, 2015