MAGNET DESIGN FOR SIAM PHOTON SOURCE II*

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Abstract

Siam Photon Source II project has been approved and detailed technical design of the accelerator system is currently in progress. The Double Triple Bend Achromat (DTBA) lattice is implemented in the storage ring design for low emittance and more space for insertion devices. Magnets with moderate to high field requirements have been designed, including combined function magnet with the field gradient of 27.1 T/m, quadrupole magnets with the field gradient up to 60 T/m and multifunction sextupole magnets. This work presents the magnet requirement and specification, design concept, recent simulation results and analysis of the magnetic field quality. A plan for prototype development is also discussed.

INTRODUCTION

Siam Photon Source is currently the only synchrotron light source in Thailand. It has been operated since 2003 with the beam energy of 1.2 GeV and the maximum beam current of 150 mA in the decay mode. There are 10 beamlines and 12 experimental stations utilizing a broad spectral range of radiation from bending magnets and insertion devices. With increasing number of users, Siam Photon Source II project was proposed and recently approved by the government. The project aims to maximize domestic industrial engagement, especially for magnets and vacuum chambers manufacturing. Magnets for the storage ring have been designed with parallel prototype development which is done predominantly in-house and also by local manufacturing industry.

With the implementation of Double Triple Bend Achromat (DTBA) lattice, the beam emittance below 1 nm·rad is obtained. The storage ring of Siam Photon Source II consists of 14 DTBA cells with the ring circumference of 321.3 m. Detailed information of the lattice design is reported elsewhere [1]. There are four normal bending magnets (BMs), two combined function magnets (DQs), a series of quadrupole magnets (QD, QF1, QF4, QF6 and QF8), multifunction sextupole magnets (SD1, SD2 and SF), octupole magnets and correcting magnets in the DTBA cell. Although a complete magnet design is in progress, design concept and simulation results of some magnets will be presented in this work.

MAGNET DESIGN

Magnet design and requirement for Siam Photon Source II is determined by several factors including beam dynamics requirement, vacuum chamber, manufacturing capability and space management. Table 1 summarizes the requirement and specification for the storage ring magnets.

Table 1: Magnet Requirement and Specification

Parameter	**BM**	**DQ**	**QD**	**QF1**	**QF4**
Field	0.87 T	0.6 T, 27.1 T/m	51 T/m	45 T/m	44 T/m
Ver. BSC (mm)	±7.2	±2.7	±7.5	±1.6	±5.1
Hor. BSC (mm)	±11.4	±7.3	±12.4	±12.0	±19.1
GFR (mm)	±14	±8	±10	±10	±16
$\Delta B/B$	1×10^{-4}	1×10^{-2}	5×10^{-4}	5×10^{-4}	5×10^{-4}
R (mm)	--	26	16	16	18
Parameter	**QF6**	**QF8**	**SD1**	**SD2**	**SF**
Field	60 T/m	50 T/m	2030 T/m^2	1140 T/m^2	1450 T/m^2
Ver. BSC (mm)	±1.5	±1.9	±7.0	±7.0	±4.9
Hor. BSC (mm)	±7.2	±8.7	±14.2	±9.4	±18.3
GFR (mm)	±10	±10	±13	±15	±15
$\Delta B/B$	5×10^{-4}	5×10^{-4}	1×10^{-3}	1×10^{-3}	1×10^{-3}
R (mm)	16	16	22	24	24

The calculated Beam Stay Clear (BSC) required to accommodate electron beam with energy deviation up to 3.5% is used as a limiting factor for the vacuum chamber design as well as the magnet Good Field Region (GFR) verification. The pole radius (R) is not a constraint but it is adjusted in the way that the required magnetic field strength and the field homogeneity within the GFR can be obtained, while maintaining the feasibility of the chamber design. Conceptual design of magnets for the Siam Photon Source II was carried out using the two-dimensional POISSON simulation software. Detailed design has been currently done in three dimensions using Radia and the results will be cross-checked with the commercial Opera-3D, although a good consistency between magnetic field values calculated from the two softwares have been reported before [2]. Figure 1 shows the magnet models created in Radia for magnetic field simulation in three dimensions. Engineering aspect is also considered in the design of magnet yoke geometry. The yoke will be made of AISI 1006 low-carbon steel. Magnet coil winding is designed such that all magnets can be installed within the space available. Preliminary vacuum chamber design employs the maximum BSC ellipse with the size of ±20 mm and ±8 mm in horizontal and vertical directions, respectively. A minimum thickness of the vacuum chamber is 1.5 mm and the magnet design must also take this into account.

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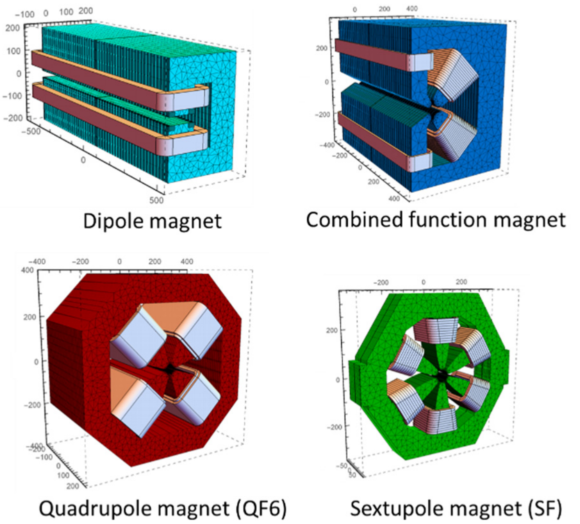
Dipole magnet
Combined function magnet
Quadrupole magnet (QF6)
Sextupole magnet (SF)

Figure 1: Magnet models created in Radia.

Dipole Magnet

The BM magnets deflect electron beam with the deflection angle of 0.087 radian and the effective length of 1000 mm. It is designed based on a C-shape type dipole to provide space on one side for vacuum chamber insertion. The moderate field of 0.87 T is achieved from a vertical gap of 30 mm, the pole width of 100 mm and the excitation of 10731 A·turns. Magnetic field homogeneity of the magnet can be controlled within 1×10^{-4} at the operating point and its ±5% margins by shimming technique. Higher-order multipole components normalized to B_1 are all below 1×10^{-4} within the radius of 14 mm.

Combined Function Magnet

The DQ magnets for Siam Photon Source II combine the bending and defocusing functions using the offset quadrupole concept based on ESRF's magnet design [3]. A quadrupole magnet with the field gradient of 27.1 T/m is displaced by 22.2 mm horizontally to provide the dipole field component of 0.6 T at the new magnet centre. Magnet poles on the unused side are made smaller with fewer turn number of coil as shown in Figure 1 to reduce power consumption. Vertical magnetic field component of the DQ magnet is plotted in Figure 2 for the operating current of 214 A.

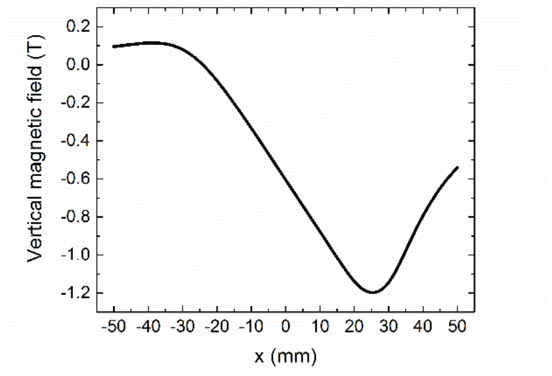

Figure 2: Vertical magnetic field of DQ magnet along the horizontal coordinate at the operating current of 214 A.

The DQ magnets are to be installed in middle of DTBA cell where the BSC is small and the GFR of only ±8 mm is required. Figure 3 shows the field homogeneity of the magnet with 10-mm chamfer at the end of the main poles. The quadrupole field error is below 1×10^{-2}, as well as the higher-order multipole components normalized to B_2. It was also found that the quadrupole gradient of DQ magnets is about ten times more sensitive than the dipole field so it could be tuned by a few percent using trim coils.

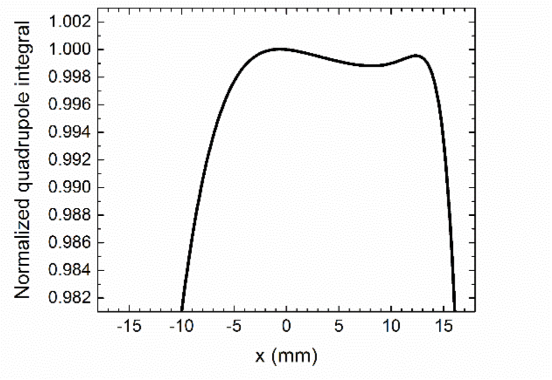

Figure 3: Normalized quadrupole integral of DQ magnet along the horizontal coordinate.

Quadrupole Magnet

The values of magnetic field gradient needed to focus electron beam range from 44 T/m to 60 T/m as listed in Table 1. QD, QF1, QF6 and QF8 magnets are located at the position where the horizontal BSC is smaller than 12.4 mm, therefore the same pole radius of 16 mm and the GFR of 10 mm are chosen. QF4 magnets, on the other hand, are located at the position where the horizontal BSC is up to 19.1 mm. Larger GFR of 16 mm and the pole radius of 18 mm are more feasible. Figure 4 presents the excitation curves of the quadrupole magnets with the turn number of 35. The quadrupole magnets are optimized between 80% to 120% of the operating values by shimming and chamfering techniques. Although they are operated near the saturation regime, the field homogeneity can be controlled within the requirement for their ±20% operation margins as illustrated in Figure 5 for QF6. Higher-order multipole components normalized to B_2 are found below 5×10^{-3}.

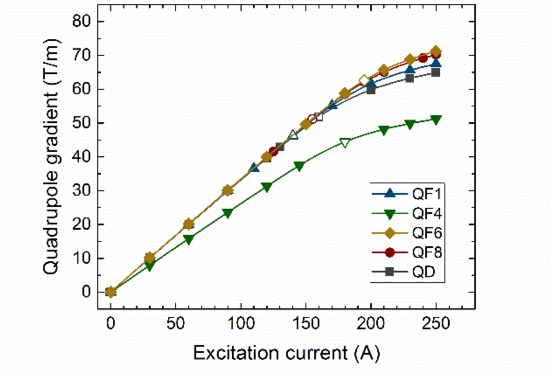

Figure 4: Excitation curves of quadrupole magnets. Open symbols indicate the operating points.

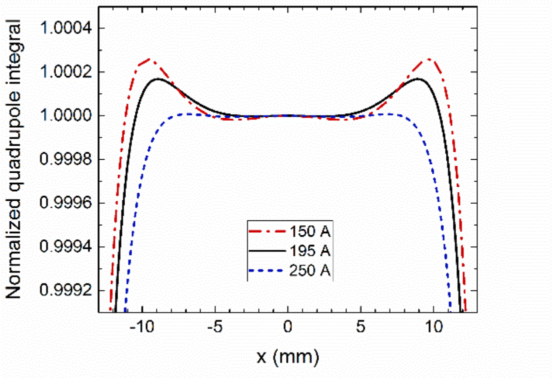

Figure 5: Normalized quadrupole integral of QF6 along the horizontal coordinate.

Sextupole Magnet

Sextupole magnets for Siam Photon Source II serves multiple purposes; sextupole field for chromaticity correction, skew-quadrupole field for coupling correction and dipole field for beam steering. There will be four sets of coils wound on the same magnet with different winding configuration. Taper design of the pole is implemented as seen in Figure 1 to reduce saturation. Required magnetic field of the sextupole magnets are 2030, 1140, and 1450 T/m^2 for SD1, SD2 and SF magnets, respectively. All magnets have the same effective length of 140 mm, thus they were originally designed to be identical with the pole radius of 24 mm. However, the magnets are later requested to be optimized up to 150% of the nominal field for future use, therefore the pole radius of SD1 is reduced to 22 mm to minimize saturation effect. Figure 6 shows the excitation curves of the sextupole magnets with the turn number of 20. The field homogeneity and higher-order multipole components normalized to B_3 are controlled within 1×10^{-3} by shimming technique.

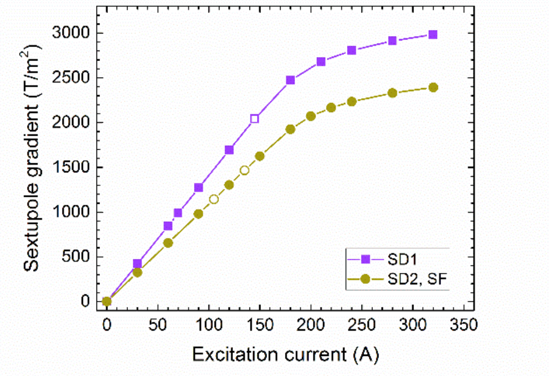

Figure 6: Excitation curves of sextupole magnets. Open symbols indicate the operating points.

It should be noted that the effects of integrated multipole errors of all magnets on dynamic and momentum apertures will need to be investigated by particle tracking simulation. Preliminary result from two-dimensional multipole errors calculated using POISSON demonstrates that the dynamic aperture becomes slightly smaller with the addition of the multipole errors. Nevertheless, the effect is much weaker than the misalignment effect.

PROTOTYPE DEVELOPMENT

In order to prepare for the construction of Siam Photon Source II, full-scale prototype of DTBA lattice is being developed. The prototype does not only include the magnet system, but also includes the girders, supports, vacuum chambers, connection and wiring, vacuum pumps and all other components within a half-cell of the lattice.

The first magnet prototype developed for Siam Photon Source II is the DQ magnet [4] which was designed with the quadrupole gradient of 30 T/m and the field homogeneity of 10^{-2} within ±8 mm. The first DQ prototype was manufactured in-house and the magnet length was limited to 300 mm due to the machining capacity. Nevertheless, the results of magnetic field measurement and coil cooling test were found in agreement with the calculation. Development of a sextupole magnet (SD1) prototype with the nominal field of 2030 T/m^2 is currently in progress. The magnet yoke is fabricated by local manufacturing company with the machining tolerance better than 20 μm. Design and construction details of this magnet are reported at this conference [5]. Remaining magnet prototype for the half-cell, including a full-length DQ magnet, is planned to be completed within 2022 before the procurement and construction of these magnets start.

CONCLUSION

Magnets for the storage ring of Siam Photon Source II project have been designed and prototype development is currently in progress. The project aims to have the magnets produced by domestic industries, therefore the prototype is necessary and needs industrial collaboration. Magnetic field quality, determined by the field homogeneity and the multipole errors, is found satisfied from the calculation. However, it will be investigated by the magnetic field measurement to confirm the result.

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