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DESIGN AND CONSTRUCTION OF SEXTUPOLE MAGNET PROTOTYPE FOR SIAM PHOTON SOURCE II PROJECT*

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Abstract

Siam Photon Source II (SPS-II) project in Thailand is the third-generation synchrotron light source. The lattice of the 3 GeV electron storage ring has been designed, consisting of 14 Double Triple Bend Achromat (DTBA) cells with the total circumference of 321.3 m. The storage ring lattice includes 56 bending magnets, 28 combined dipole and quadrupole magnets, 224 quadrupole magnets and 84 multi-function sextupole magnets. This paper presents the design and construction of a sextupole magnet prototype for SPS-II project. Magnet prototype was designed with the magnetic field gradient of 2,030 T/m^2 and includes functions of skew-quadrupole, horizontal and vertical correctors. The magnetic core is made of S10C low-carbon steel. A prototype of sextupole magnet has been constructed. All dimensional tolerances are within the range of ±20 µm.

INTRODUCTION

The new SPS-II project is the third-generation synchrotron light source. It is designed and planned to be constructed by the Synchrotron Light Research Institute (SLRI), Thailand. The new light source will have a much smaller electron beam emittance, high brightness, high precision magnets and high precision alignment. The DTBA cell consists of 4 bending magnets (BM), 2 combined dipole and quadrupole magnets (DQ), 16 quadrupole magnets (2-QF1, 4-QF4, 2-QF6, 2-QF8, 6-QD) and 6 multi-function sextupole magnets (2-SF, 2-SD1, 2-SD2) [1, 2]. This work presents the design and construction of a sextupole magnet prototype. The magnet prototype has a sextupole gradient of 2,030 T/m^2, a skew-quadrupole gradient of 0.72 T/m and horizontal and vertical corrector fields of 0.057 T. The pole radius is 24 mm and the magnetic core is made of low-carbon solid steel. Furthermore, all of the dimensions and tolerances of the magnet prototype are defined in the specifications.

MAGNET DESIGN

Sextupole magnets (SMs) for the SPS-II project is designed to correct chromaticity of the electron beam. The first prototype of SMs is defocusing sextupole magnet (SD1) with specifications and important parameters summarized in Table 1. The magnet will also have additional skew-quadrupole and corrector windings on the same pole, as illustrated in Fig. 1, for coupling correction and beam steering. Magnet coils are designed such that they can be inserted and fit in the space available. The coils consist of sextupole coil (SC), skew-quadrupole coil (SQ), vertical corrector coil (VC) and horizontal corrector coil (HC). Magnet coils at the centre poles are 20 turns of SC, 60 turns of HC and 18 turns of SQ. Magnet coils at the other poles are 20 turns of SC, 60 turns of VC, 30 turns of HC and 9 turns of SQ.

Table 1: Specifications of the SD1 Prototype

Parameter	Value	Unit
Sextupole gradient	2,030	T/m^2
Effective length	140	mm
Physical length	124	mm
Pole radius	24	mm
Pole end chamfer	2.8	mm
Hor. Beam stay clear	±14.2	mm
Ver. Beam stay clear	±7	mm
Good field region	±15	mm
Field homogeneity	1×10^{-3}	
Excitation current	215	A
Number of turns per pole	20	
Conductor dimension	7.5×7.5	mm^2
Cooling hole diameter	4	mm
Number of cooling channels	6	
Coolant water flow	1.52	l/min
Temperature rise	1.96	°C
Pressure drop	0.18	MPa
Skew-quadrupole gradient	0.72	T/m
Horizontal corrector field	0.057	T
Vertical corrector field	0.057	T
Conductor dimension for SQ, VC and HC	3×4	mm^2

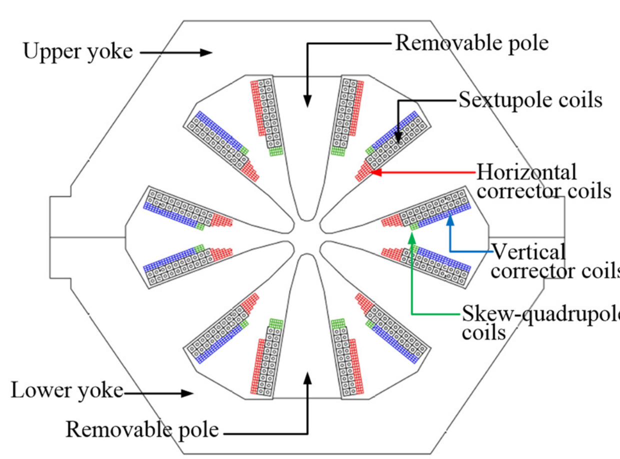

Figure 1: Schematic drawing of the SD1 prototype.

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MAGNETIC FIELD SIMULATION

The magnetic field of SD1 prototype is calculated using the three-dimensional Radia simulation software [3]. The excitation curve of the magnet with 24 mm pole radius and the turn number of 20 turns per coil is plotted in Fig. 2. The magnetic core material for the first prototype is S10C low-carbon steel. At the operating point, where the sextupole differential gradient is 2,030 T/m^2, the magnet enters the non-linear or the saturation region. Although the field quality can be controlled to meet the requirement within ±20 % margins, a possibility of sextupole magnet operation at higher field is currently considered. Therefore, reducing the pole radius will be carried out in the next designing step to reduce the saturation effect.

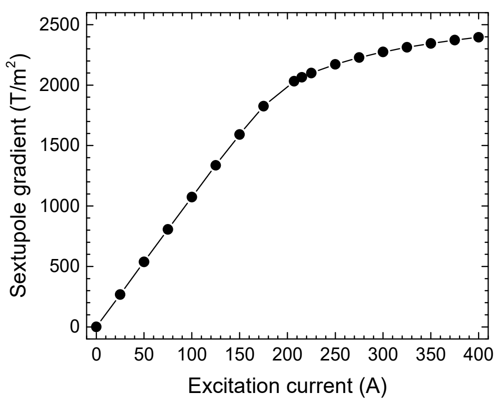

Figure 2: Excitation curve of the SD1 prototype calculated in Radia software.

Figure 3 shows the field homogeneity of the prototype at the operating current of 215 A and at ±20 % operation margins. The sextupole field integral is adjusted by chamfering the poles at both ends of the magnet. The optimum chamfer size is 2.8 mm which results in the integrated sextupole field deviation less than 1×10^{-3} within ±15 mm good field region. Systematic multipole errors of the prototype normalized to B_3 are plotted in Fig. 4. The value of all higher-order multipole terms is less than 1×10^{-4}.

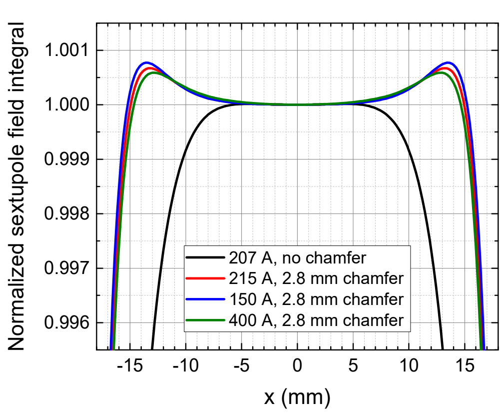

Figure 3: Normalized sextupole field integral of the SD1 prototype calculated in Radia software.

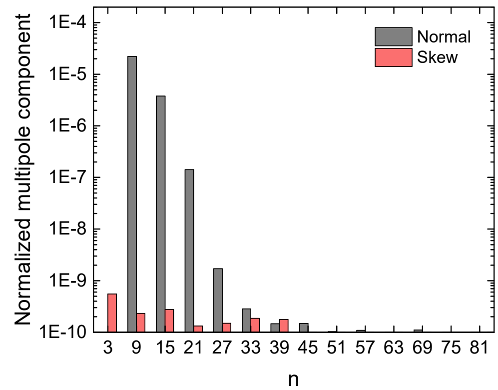

Figure 4: Systematic multipole error normalized to sextupole component of SD1 calculated in Radia software.

STRUCTURAL SIMULATION

The analysis of magnetic core deformation considers several forces including magnetic forces [4] and gravity forces of the magnet poles, magnet yokes and magnet coils. It is important to minimize the magnetic core deformation. This work presents the deformation caused by the gravity forces of the magnet poles, magnet yokes and magnet coils. The structural analysis of the SD1 prototype is calculated using the ANSYS mechanical simulation software, version R19.1 [5]. It was found that the maximum total deformation of magnetic core is within the range of 2.4 µm as shown in Fig. 5.

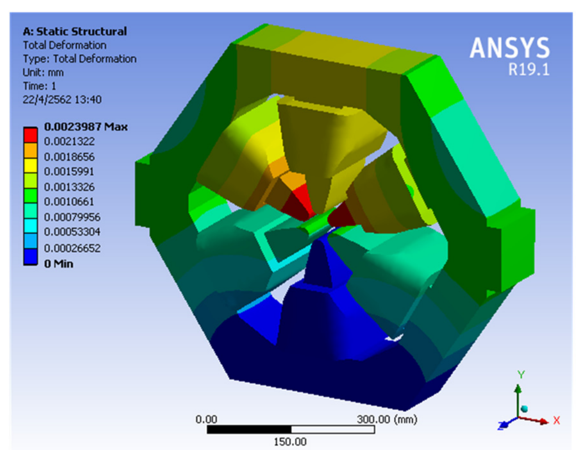

Figure 5: Magnetic core deformation of the SD1 prototype simulated in ANSYS software.

MECHANICAL DESIGN

Space between the yoke of sextupole and quadrupole magnets in the DTBA lattice is approximately 92 mm, which is small for the magnet coil assembly. Therefore, the size of magnet coils along the magnet length needs to be as small as possible. There are six sextupole coils electrically connected in series. The cooling system consists of six parallel coolant circuits. There is a set of alignment marks on the top surface of the yoke. Three-dimensional model of

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the SD1 prototype created by SOLIDWORKS software is shown in Fig. 6. The overall dimensions of magnetic core are 750 mm wide, 124 mm long and 636 mm high.

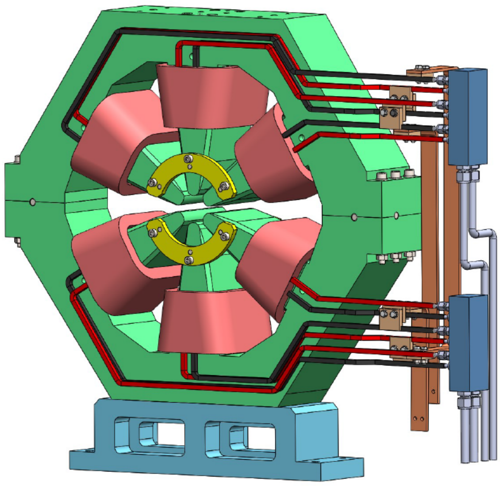

Figure 6: Three-dimensional model of the SD1 prototype.

MAGNETIC CORE CONSTRUCTION

Milling and grinding techniques are used for magnetic core manufacture with the final machining by the wire cutting electrical discharge machining (WEDM) device [6]. Figure 7 shows the dimensional inspection using the coordinate measuring machine (CMM) to ensure that the accuracy of magnetic core manufacture is within the requirement. The magnetic core is made of S10C low-carbon solid steel. The yoke is assembled from upper and lower half-yokes, each with a removable pole for coil assembly. The removable pole has two pins, four bolts and two pole clamps to fix the position within a half-yoke. The magnetic core is assembled with four assembly pins and six bolts. The magnet support is made of SUS304 stainless steel. Figure 8 shows the magnetic core of the SD1 prototype. All dimensions and tolerances of the magnetic core and the pole profile are within the specifications of ±20 µm.

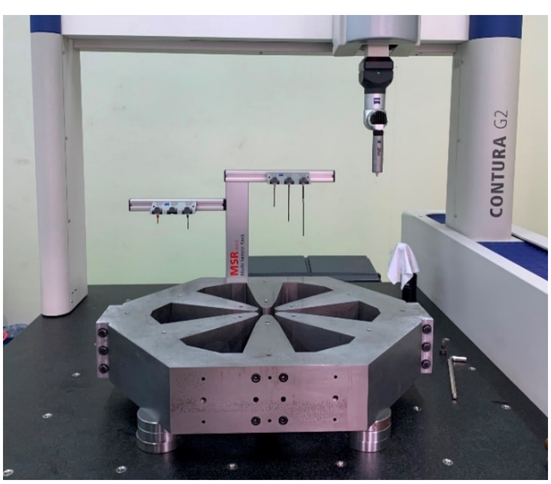

Figure 7: Dimensional inspection of the SD1 prototype by coordinate measuring machine.

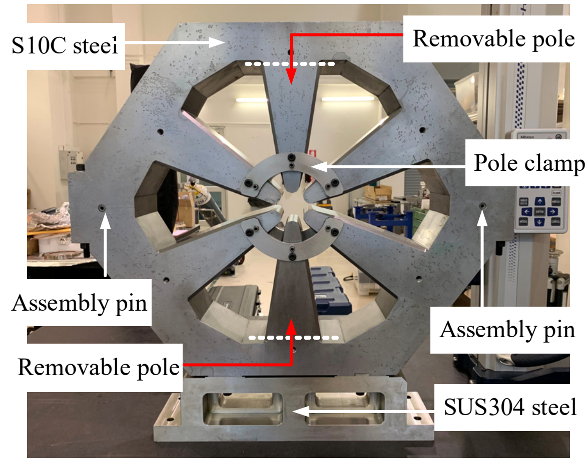

Figure 8: Magnetic core of the SD1 prototype.

CONCLUSION

A prototype of the multifunction sextupole magnet for the SPS-II storage ring was designed and constructed. The design process uses Radia simulation to determine the pole profile and magnet geometry for the required magnetic field quality and magnetic effective length. ANSYS simulation is used for structural analysis of the magnetic core deformation. The construction of the magnetic core is completed, with all dimensions and tolerances within the range of ±20 µm. Magnetic field and multipole field components of the magnet will be measured, with the application of pole end chamfer for investigation and improvement of the three-dimensional magnetic field quality.

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