DESIGN OF THE MAGNET SYSTEM FOR THE SUPER SOR LIGHT SOURCE

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Abstract

The Super SOR light source is a future Japanese high-brilliance synchrotron radiation source in the vacuum ultraviolet and soft X-ray region. The storage ring lattice requires 28 dipoles with a maximum field of 1.25 T, 144 quadrupoles and 112 sextupoles with maximum strength of 23 T/m and 400 T/m^2, respectively. In this paper, designs and specifications of these lattice magnets are presented.

INTRODUCTION

The Super SOR light source [1], a Japanese 3rd generation vacuum ultraviolet and soft X-ray light source, is being planned to construct at Kashiwa campus of the University of Tokyo and designed by the nationwide collaboration of accelerator physicists and synchrotron radiation users. The light source is 1.8-GeV electron storage ring with a circumference of 280 m and a nominal emittance of 7.3 nm·rad. The ring consists of 14 double bend achromat cells and has two 17-m long straight sections and twelve 6.2-m straight sections [2]. Except for two 6.2-m sections for beam injection and rf cavities, the straight sections are utilized for various kinds of insertion devices.

The ring contains 28 dipoles, 144 quadrupoles and 112 sextupoles. All the magnet cores will be made of 0.5-mm thick laminated silicon-steel. The required field qualities of the magnets are as follows; (1) the maximum fields of 1.25 T for the dipole, 23 T/m for the quadrupole and 400 T/m^2 for the sextupole, (2) horizontal good field regions of ± 30 mm for dipole and ± 25 mm for the quadrupole and sextupole, (3) field uniformity of 5×10^{-4} within the good field region.

Presented in this paper are designs and specifications of the lattice magnet system. The shapes of the magnets were determined using the POISSON (2D) and ELF/MAGIC (3D) codes to satisfy the requirements mentioned above. In all cases, designs of the magnets are optimized for nominal operation energy of 1.8 GeV, but they are capable of reaching a maximum energy of 2.0 GeV.

DIPOLE

Figure 1 shows the cross-sectional and top views of the dipole magnet. The dipole has a C-type rectangular configuration and bending radius of 5.348 m. In order to attain the large good field region, the magnet poles have shims of 0.7-mm thickness at the edges. The gap height of 52 mm (50.6 mm between shims) is determined taking into account the vacuum chamber size and required clearances.

Main parameters of the dipole are summarized in Table 1.

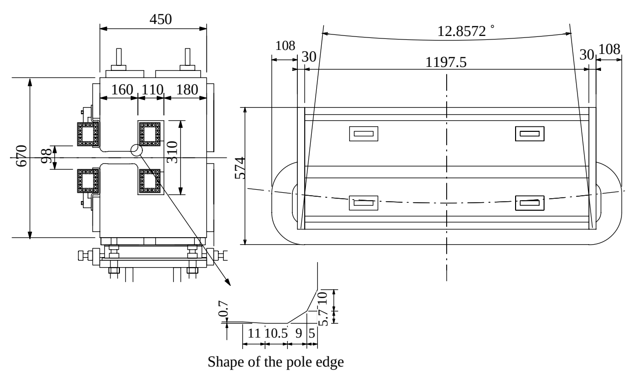

Figure 1: The dipole magnet.

Table 1: Main parameters of the dipole magnet.

Core length [m]	1.1975
Field strength [T]	1.122 (1.8 GeV)
	1.247 (2.0 GeV)
Bending angle [degree]	12.857
Gap height [mm]	52
Turns/pole	30
Conductor size [mm]	15×16-ϕ9
Max. current [A]	1000
Max. current density [A/mm^2]	5.7
Resistance [mΩ/mag]	20
Max. voltage [V/mag]	20.0
Max. Power [kW/magnet]	20.0
Number of water circuits	6
Water flow [l/min]	65.4
Water pressure drop [kg/cm^2]	4
Max. temperature rise [˚C]	4.4

Figures 2 shows the calculated excitation curve and Ampere-turns (AT) factor of the dipole. The saturation at the excitation for 2.0 GeV is roughly 6 %. Field uniformity for various excitation levels is shown in Fig. 3. The uniformity better than 3×10^{-4} is obtained within ±30 mm at the all excitation levels in this figure.

In our previous study using some model magnets, good agreement between calculated and measured field

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distributions of dipoles has been confirmed [3]. So we can assume that the field quality of the designed dipole can fulfil the requirements.

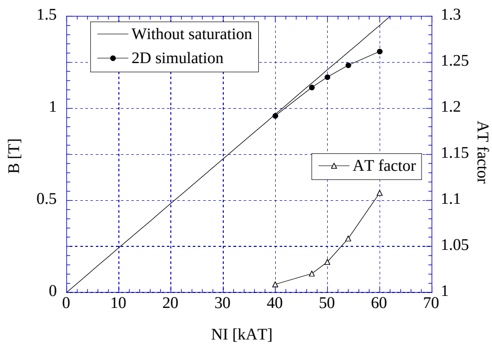

Figure 2: Excitation curve and AT factor of the dipole.

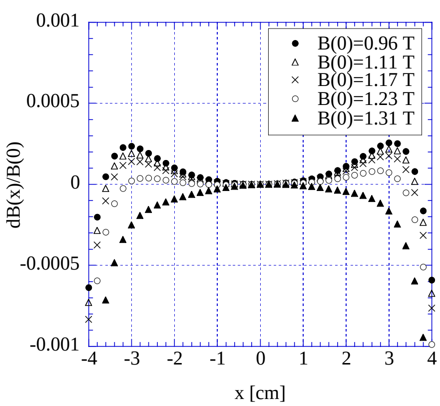

Figure 3 : Field uniformity of the dipole

QUADRUPOLES

The Super SOR ring has 144 quadrupoles consisting of 9 families (or 12 families depending on the operational mode of the ring optics [2]) and two different core lengths, 0.2 m and 0.3 m. Figure 4 shows the cross sectional and side views of the 0.2-m quadrupole together with the pole profile. The bore diameter is 70 mm. The linear shim is adopted to the pole edge to improve the extent of the good field region. All the quadrupoles have the same cross section as shown in Fig. 4 except those installed in the downstream sections of the dipoles. For such quadrupoles, shape of return yoke is partially modified to avoid interference with synchrotron radiation beamlines.

The parameters of the quadrupoles are summarized in Table 2.

Figure 5 shows the excitation curves calculated by the 2D and 3D simulations. Because of the short core lengths, the 3D effect on the field excitation is remarkable. However, it is also obvious that the required maximum field strength can be achieved by taking into account the effective length, which is approximately given by the sum of the core length and the bore radius.

The field gradient distribution of the quadrupole is shown in Fig. 6. The uniformity within the requirement is achieved over wide range of excitation.

Mechanical deformation of the quadrupole due to the magnetic force and weight of the magnet itself was estimated by 2D FEM analysis using ANSYS. The maximum displacements at the pole tip were 0.4 µm and 1.0 µm for excitations of 5 kAT and 14 kAT, respectively.

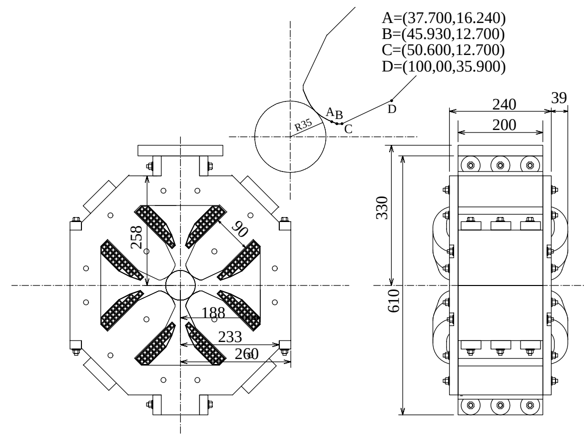

Figure 4: The quadrupole magnet.

Table 2: Main parameters of the quadrupole magnet.

Family	QF, QD, Q1, Q3, Q1L, Q4L	Q2, Q2L, Q3L
Number of magnets	112	32
Core length [m]	0.2	0.3
Max. field strength [T/m]	23	23
Bore diameter [mm]	70	70
Turns/pole	28	28
Conductor size [mm]	9×9-ϕ6.5	9×9-ϕ6.5
Max. current [A]	500	500
Max. current density [A/mm^2]	10.5	10.5
Resistance [mΩ/mag]	35	45
Max. voltage [V/mag]	17.5	22.5
Max. Power [kW/magnet]	8.8	11.3
Number of water circuits	4	4
Water flow [l/min]	24.1	22.0
Water pressure drop [kg/cm^2]	5	5
Max. temperature rise [˚C]	5.2	7.3

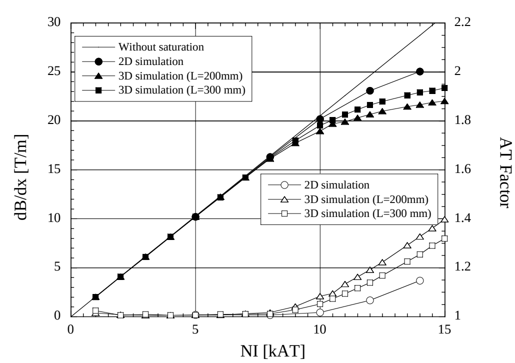

Figure 5: Excitation curve and AT factor of the quadrupole.

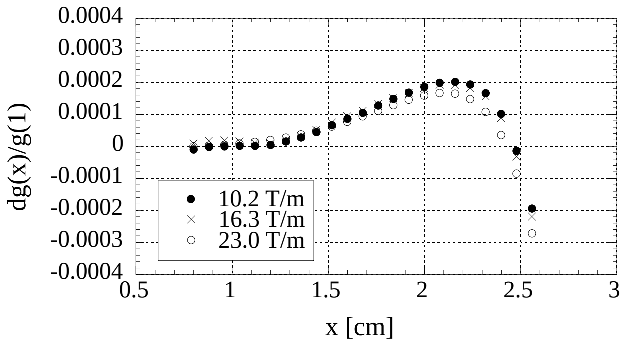

Figure 6: Field uniformity of the quadrupole magnet.

SEXTUPOLE

The storage ring has 112 sextupoles, which are divided into 4 (or 8) families. All the sextupoles have an identical cross section but there are two different core lengths, 0.1 m and 0.15 m. Figure 7 shows the sextupole of 0.1-m core length. The main parameters of the sextupoles are listed in Table 3. Since the power consumption per magnet is small, the indirect cooling method is adopted to cool the coils.

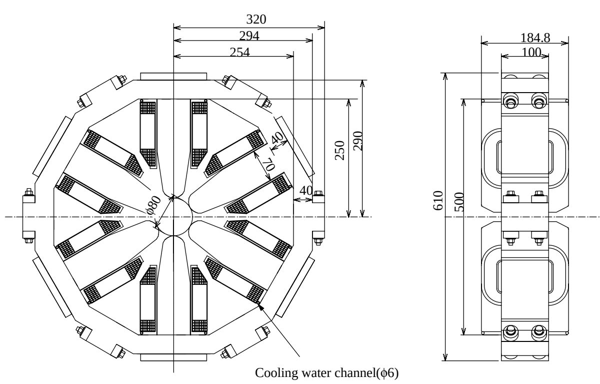

Figure 7: The sextupole magnet.

Table 3: The design parameters of the sextupole magnet.

Family	SF, SD	S1, S2
Number of magnets	56	56
Core length [m]	0.1	0.15
Max. field strength [T/m^2]	400	400
Bore diameter [mm]	80	80
Turns/pole	169	169
Conductor size [mm]	3.5×5.5	3.5×5.5
Max. current [A]	20.1	20.1
Resistance [mΩ/mag]	548	663
Max. voltage [V/mag]	11.0	13.3
Max. Power [kW/magnet]	0.221	0.268
Number of water circuits	6	6
Water flow [l/min]	3.6	3.2
Mean temperature rise [˚C]	12	16

Figure 8 shows the excitation curve of the sextupole. The contribution of the end field is expected to be large due to the short core length. Therefore, the design has a large margin to obtain the required maximum field strength of 400 T/m^2.

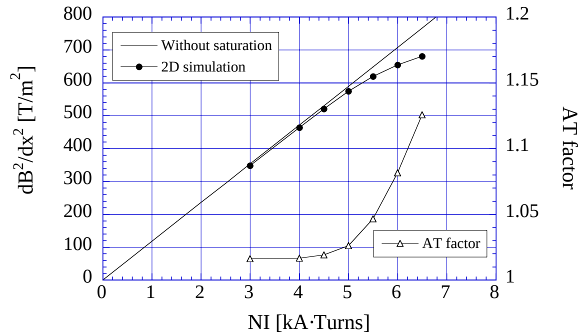

Figure 8: Excitation curve and AT factor of the sextupole.

POWER SUPPLIES

The dipoles will be electrically connected in series and powered by one large power supply with thyristor rectifiers. On the other hands, all the quadrupoles and sextupoles will be individually powered for operational flexibility using compact switching-mode power supplies. Parameters of the dipole power supply and the typical quadrupole power supply are listed in Table 4.

Table 4: Parameters of the magnet power supplies.

	Dipole PS	Quadrupole PS
Input voltage	3ϕ, 400 V	3ϕ, 400 V
Max. output voltage [V]	600	30/20
Max. output current [A]	1000	500/250
Max. output power [kW]	6	15/5
Current ripple	< 10 ppm p-p	< 10 ppm p-p
Current stability / 8hrs.	< 10 ppm p-p	< 10 ppm p-p
Power converter type	Thyristor with active filter	Switching mode converter
Power factor	0.85	0.95
Efficiency [%]	95	90

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