INTRODUCTION TO HLSII STORAGE RING CONVENTIONAL MAGNETS *

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Abstract

HLS (Hefei Light Source) is a dedicated synchrotron radiation research facility, whose emittance is relatively large. In order to improve the performance of HLS, especially getting higher brilliance synchrotron radiation and increasing the number of straight sections for insertion devices, an upgrade project named HLSII will be preceded soon. The storage ring lattice comprises 8 dipoles, 32 quadrupoles and 32 combined function sextupoles. Design and analysis of the magnets are showed in the paper. The multipurpose combined function magnet is the first one designed and used in China. Mechanical design and fabrication procedures for the magnets are presented also.

INTRUCTION

In order to get more straight sections for insertion devices and obtain higher brilliance synchrotron radiation, an upgrade project named HLSII will be preceded soon. The new storage ring's circumference is same to that of the current one but the focusing structure is different. For the upgrade project, the new ring will be installed on current ground settlement and all of the magnets will be reconstructed. Magnet field quality is strict for the new storage ring. For the dipoles, quadrupoles and the sextupoles, the systematic and random tolerances for the harmonic contents in the good field regions are required to be in the order of 10^{-4}, Magnetic fields of all magnets have been calculated using POISSON codes [1] and Opera-3d codes[2]. The dipole and quadrupole magnets will be chamfered at the ends to meet the integrated field quality specifications. Size of the chamfering will be determined according to the magnetic measurement result of prototypes.

STORAGE RING MAGNETS

The c-shape dipoles of the HLSII storage ring have arc structure and the quadrupoles and sextupoles are straight magnets. Extraction of the synchrotron radiation and the accommodation of the vacuum chamber have been accounted. The yokes are made of J23-50 steel laminations compressed using end plates and longitudinal plates. In order to avoid magnets requiring coils with large cross section, the magnet coils are water cooled which requires the use of conductors with cooling channels. In addition to the main coils, there are trim coils in the dipoles. The technical requirement of the magnet is given in Table 1.

Table 1: Technical Requirement for Storage Ring Magnets

Type	Dipole	Quadrupole	Sextupole
Operation Fields	B_y=1.2336T	G_y=13.0 T/m	K_y=330 T/m^2
Good Field Region	X=±38m	R=38 mm	R=38 mm
Integral Field Errors @|X|≤38mm	0.5‰	0.5‰	2.0‰
Higher Harmonics Errors @R=38 mm	0.3‰	0.4‰	1.0‰
The rms Dispersions	0.1%	0.3%	0.3%

Dipole Magnets

For HLSII lattice, there are 8 dipole magnets and each magnet should bend 45 degree compared to the previous 30 degree. Accounting to the extraction of the synchrotron radiation and space for the vacuum chamber, c-shape configuration has been chosen which can provide good stiffness and field quality. The dipoles are made of one-piece laminations and will be installed after the vacuum chamber is in place. Main coils of all dipoles are powered in series and the trim coils are adjusted individually to reduce the inconsistency. The schematic diagram of the dipole is given in Fig.1. The major parameters for the magnet are given in Table 2.

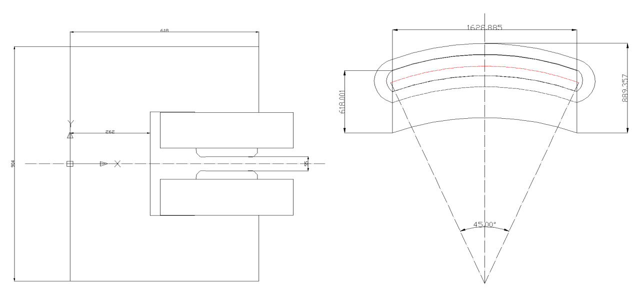

Figure 1: End view and overhead view of the dipole magnet.

Since the effective magnetic length 1.7 m is longer, the sagitta of the orbit is very large. If the core of the magnet is made straight along the orbit, the pole width should be needed to increase in order to include the sagitta which results in a bulky and heavy magnet. To avoid this problem, the pole should be curved following the trajectory. The pole gap is 55mm which is determined by the vacuum chamber. The pole width is 210mm. The good field region extends horizontally from -38mm to 38mm in respect to the pole reference line and vertically from -20mm to 20mm.

The 2D and 3D magnetic analysis has been performed respectively using the two-dimensional POISSON codes

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and OPREA codes. The magnetic field in the gap is 1.233 Tesla and the efficiency is above 98%.The magnetic tolerances of the good field region could be in the order of 10^{-4} through optimizing the shape of the pole tip. There are three racetracks of the main coils and one racetrack of the trim coil on each pole. Each main coil with 42 turns in 3 layers is made of a 20mm×14mm conductor with a 7mm diameter water-cooling channel. The main coils of each are insulated with a 0.5mm thick and each layer a 2mm thick Dacron tape.

Table 2: Parameters for the Storage Ring Dipole Magnet

Parameters	Value
Energy(MeV)	800
Quantity of magnet	8
Bending radius(m)	2.16451
Gap flux density(T)	1.2336
Gap height(mm)	55.0
Good field width(mm)	76
Good field height(mm)	40
Magnetic efficiency	0.981
Conductor size(mm)	20×14ø7
Ampere-Turns per pole(AT)	27975.1
Current(A)	666.074
Resistance per magnet(Ω)	0.0283
Inductance per magnet(mH)	101.4
Core weight per magnet(t)	6.376
Copper weight per magnet(t)	0.855
Water circuit	6
Water pressure drop(kg/cm^2)	5
Water flow rate per magnet(l/min)	22.55
Temperature rise(C)	7.96

Quadrupole Magnets

There are 32 quadrupoles with 2 different lengths 0.2m and 0.3m. All of the quadrupoles have the same bore diameter 94mm determined by the vacuum chamber. The quadrupoles are powered independently to regulate conveniently and reduce the requirement of the consistence of the magnets. The cross section and the main coils of the quadrupoles are designed with the same requirement and the maximum gradient is 13.1T/m. The major parameters of the quadrupoles are given in Table3; The magnet cross section is shown in Fig.2.

The shape of the pole tip is optimized with the conformal mapping and the 2D magnetic analyses have been performed using the two-dimensional POISSON group computer codes. The higher harmonics could be controlled by 0.04%.

Two quadrants are assembled as half magnets, each top and bottom. The laminations are shuffled to ensure uniform magnetic property after precise punching and accurately stacked during the magnet construction [3]. The contour dimensions of the lamination are precisely

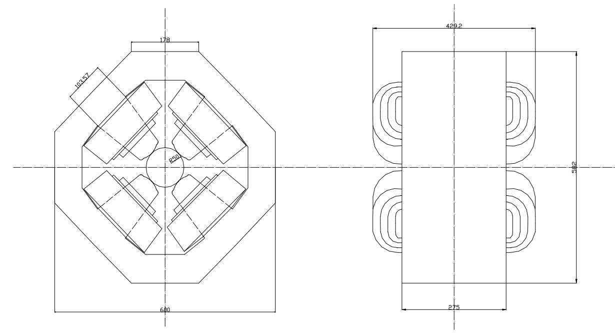

Figure 2: End view and overhead view of the quadrupole magnet.

Table 3: Parameters for the Storage Ring Quadrupole Magnet

parameters	Value	
Quantity of magnet	24	8
Inscribed radius(mm)	47	
Maximum magnetic gradient (T/m)	13.0	
Magnetic length(m)	0.30	0.20
Good field radius(mm)	38	38
Ampere-Turns per pole(AT)	12482.0	13038.0
Current(A)	201.32	210.30
Conductor size(mm)	7×7ø4	
Resistance per magnet(Ω)	0.122	0.096
Inductance per magnet(mH)	43.8	32.0
Core weight per magnet(kg)	385	233.33
Copper weight per magnet(kg)	108.7	85.35
Water circuit	4	
Water pressure drop(kg/cm^2)	5	
Water flow rate per magnet(l/min)	3.84	4.176
Temperature rise(C)	18.5	14.52

controlled to within 25μm. However, magnet assembly accuracy is controlled within 30μm. The top and bottom halves are aligned relative to each other with precise circular holes and pins. The two magnet halves should be keyed with respect to each other in the longitudinal direction with an accuracy ±0.05 mm. The reproducibility of the position after the reinstallation should be controlled within 30μm. Meanwhile, the magnet can be removed without taking out the vacuum chamber. Magnets are accurately fixed on girder and without alignment. A precise reference base plate is attached to the quadrupole magnet.

On each pole, there are three racetracks of the main coils with different size. The main coil with 62 turns in 3 layers is made of a 7mm×7mm conductor with a 4mm diameter water-cooling channel.

Combined Function Sextupole Magnets

HLSII storage ring has 32 sextupoles with the same length, the same bore diameter 100mm, and the same cross section. The multifunctional sextupole magnet is the first one designed and used in China. The sextupole magnetic field is designed for natural chromaticity correction and also to producing a horizontal and vertical magnetic field for the beam orbit distortion correction and a skew quadrupole magnetic field for adjusting the transversal coupling of the storage ring. A conventional sextupole magnet type is chosen. The magnet is divided into three parts. The cross section is shown in fig.3.

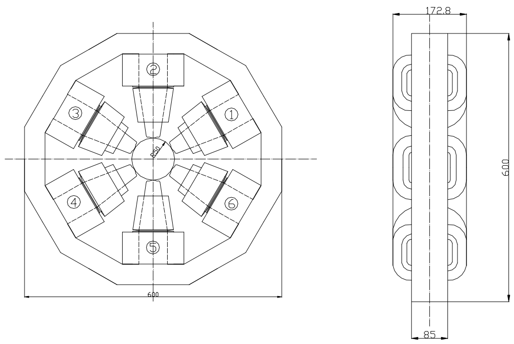

Figure 3: End view and overhead view of the sextupole magnet.

According to Halbach perturbation theory [4], the first order perturbation effects in iron-dominated 2-D symmetrical magnets are expressed in terms of generation or changes in multipole coefficients.

If a vertical dipolar field is required, which can be obtained by using the six dipolar coils shown in Fig. 3, the coils corresponding to the poles 1, 2, 3 are of opposite polarity to those of 4, 5, and 6. From symmetry, we will give the same current I_1 to the coils 1, 3, 4 and 6 and the same current I_2 to the coils 2 and 5, and the $I_2 = 2I_1$.

In the case of horizontal dipolar field, it can be obtained by using four dipolar coils driven by the same current I_3. The coils of the poles 1 and 6 are of opposite polarity to those of 3 and 4.Coils 2 and 5 are not used in this case.

As for the skew quadrupole, we can use two coils on poles 2 and 5 with the same polarity, driven by the same current I_4, and the poles 1,3,4,6 with the opposite polarity to those of 2 and 5, drive by the same current I_5.

The 2D and 3D magnetic analyses have been performed for different exciation currents using POISSON and Opera-3d codes respectively. The shape of the pole tip is optimized with the conformal mapping and the straight line. The major parameters of the sextupoles are given in Table 4.

The yoke of the sextupoles consists of three sections with the same size. On each pole, there are three racetracks of the main coils. The main coil with 30 turns in 3 layers is made of a 6.5mm×6.5mm conductor with a 3.3mm diameter water-cooling channel.

END CHAMFERING

Magnet uniformity specifications typically require the integrated field to be uniform, have a uniform integrated gradient or to have a uniformly parabolic field integral for the dipole, quadrupole or sextupole, respectively [5]. In order to achieve a uniform field integral, it is necessary that the magnet effective length does not change with transverse position. As for the dipole, the size of the chamfer is different along the transverse direction. We will use a straight angled machined cut at the end of the quadrupole pole tip. The simple cut removes the most material from the center of the pole. The depth of the cut decreases as one nears the edge of the pole. The real size of the chamfer of the dipole and quadrupole would be determined by the result of the measurements.

Table 4: Parameters for the Storage Ring Sextupole Magnet

parameter of the main coils	Value
Quantity of magnet	32
Inscribed radius(mm)	50
Max.sextupole $K=d^2B/dx^2(T/m^2)$	330
Magnetic length(m)	0.125
Good field radius(mm)	38
Ampere-Turns per pole(AT)	6376.0
Current(A)	212.6
Conductor size(mm)	6.5×6.5ø3.3
Resistance per magnet(Ω)	0.0536
Inductance per magnet(mH)	7.5
Core weight per magnet(kg)	120.0
Copper weight per magnet(kg)	92.5
Water circuit	3
Water pressure drop(kg/cm^2)	5
Water flow rate per magnet(l/min)	2.214
Temperature rise(C)	15.2

SUMMARY

In this paper, the magnet system for the HLS storage ring upgrade project is described. The field design of all the magnets gives a few 10-4 of the multipoles and the integrated field qualities. Chamfering of the magnet ends will be determined by the magnetic measurements of the prototypes. The mechanical design of the magnets has been finished. All of the prototypes will be finished in May 2011.

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