ISBN: 978-3-95450-207-3 doi:10.18429/JACoW-MEDSI2018-TUPH38

PRELIMINARY DESIGN OF THE MAGNETS OF HALS*

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Abstract

The Hefei Advanced Light Source (HALS) is a future soft X-ray diffraction-limited storage ring at National Synchrotron Radiation Laboratory (NSRL) of China. This project aims to improve the brilliance and coherence of the X-ray beams and to decrease the horizontal emittance. The lattice of the HALS ring relies on magnets with demanding specifications, including combined function dipole-quadrupoles (DQs) with high gradients, longitudinal gradient dipoles (DLs), high gradient quadrupoles and sextupoles. All these magnets have been designed using Radia and POSSION, as presented in this paper.

INTRODUCTION

Hefei Light Source (HLS) at National Synchrotron Radiation Laboratory is a dedicated secondary generation VUV and soft X-ray light source. The upgrade of HLS was completed in 2014 and the performance has been improved a lot. With the development of accelerator technologies and requirements from the user community, a new light source named Hefei Advanced Light Source (HALS) was brought forward about three years ago. HALS will be a soft X-ray diffraction-limited storage ring. Pre-research project of HALS was funded by Chinese Academy of Sciences and Anhui Province of China in 2017. Most key technologies, such as lattice design, vacuum, magnet, radio frequency, will be studied in the next two years.

According to the accelerator physics design, longitudinal gradient dipoles, combined dipole quadrupoles, quadrupole and sextupole magnets will be studied and prototypes of them will be constructed. Preliminary design of them will be stated in this paper.

STORAGE RING OF HALS

The lattice of the HALS has been studied using a new concept of multi-bend achromatic (MBA), locally symmetric MBA, which can promise large dynamic aperture and momentum acceptance [1,2]. Main Parameters of the HALS is shown in Table 1. It should be noted that the lattice is still evolving, and the parameters will be changed with it.

Table 1: Main Parameters of HALS

Parameter	Value	Units
Energy	2.4	GeV
Average current	300	mA
Natural emittance	18.4	pm·rad
Circumference	~680	m
Number of cells	32	-
Long straight section	5.1	m
Energy loss per turn	220	keV

MAGNETS OF HALS

In the MBA lattice of HALS, high gradient quadrupole magnets are used to compress the beam emittance, sextupole magnets are used to correct the chromaticity, longitudinal gradients dipole magnets (DLs) are used to bend the beam and weaken the negative effect of sextupole on dynamic aperture, and combined dipole-quadrupoles (DQs) are good for saving space. The magnets need to be studied are shown in Table 2.

Table 2: Magnets of HALS

	DL	DQ	Quad	Sextu
Field strength	0.2~0.5T	0.5T 25T/m	80T/m	4000T/m^2
Bore diameter	26 mm			
Reference radius	3 mm			
Homogeneity	5×10^{-4}	5×10^{-4}	5×10^{-4}	1×10^{-3}

All magnets except the DL should be optimized to improve the field quality. The shape optimization method developed in ESRF [3] was adopted. Pole profiles of the magnets are parameterized using Legendre polynomials. A cost function such as the sum of multipole field are reduced with Newton-Gauss iteration until the optimized profile is obtained.

Longitudinal Gradient Dipole

Permanent magnets (PM) have drawn much attention in recent years, although there exist some challenges such as the variation of remanent field with the temperature and radiation damage. The greatest advantage of PM is the almost zero operation cost. So, we design a PM based longitudinal gradient dipole, as shown in Fig. 1.

The DL magnet has seven modules. All modules have the same gap and pole shape but are filled with different amounts of permanent magnet volumes to achieve the longitudinal field gradient. The PM material used for the

* Work supported by Chinese Academy of Sciences and Anhui Province
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ISBN: 978-3-95450-207-3 doi:10.18429/JACoW-MEDSI2018-TUPH38

DL is Sm_2Co_{17} due to its resistance to radiation damage and temperature stability [4]. To achieve higher temperature stability, a passive temperature compensation system based on Fe-Ni shunts [5] will be studied. Structure modification to add the field tunability will also be considered.

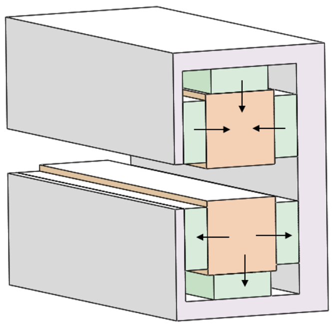

Figure 1: One module of the PM dipole.

The field along the DL and homogeneity of field integral are shown in Figs. 2 and 3 respectively. The fields of the seven modules ranges from 0.2 to 0.5 T. The error of field integral is less than 1×10^{-4}.

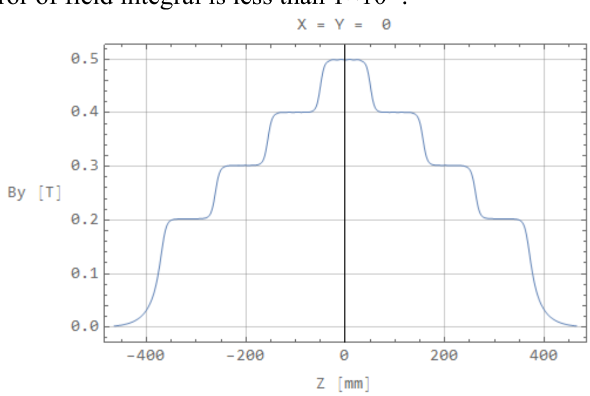

Figure 2: Field versus longitudinal position.

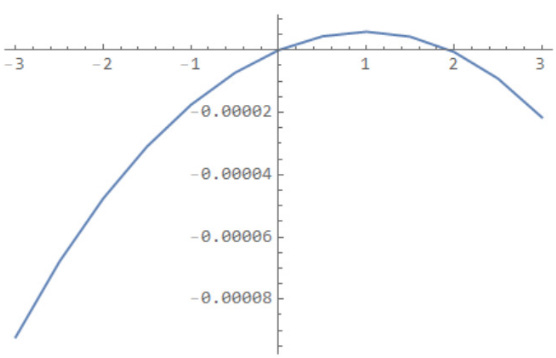

Figure 3: Homogeneity of field integral.

Combined Dipole Quadrupole

The central field of the DQ is 0.5 T, while the field gradient is 25 T/m. Because of the high field gradient, tapered dipole isn't appropriate and offset quadrupole was adopted. The offset distance is 20 mm and the beam chamber is completed located in the right side of the magnet bore, as shown in Fig. 4 (a). To maintain a gap between the pole and out wall of the beam chamber, bore diameter of the quadrupole should be more than 49 mm. The size of the left auxiliary poles, which improve the field quality, can be reduced to decrease the construction and operation cost. Recent work showed that the auxiliary poles may be substituted by a septum plate made of soft iron. Further research on it will be performed.

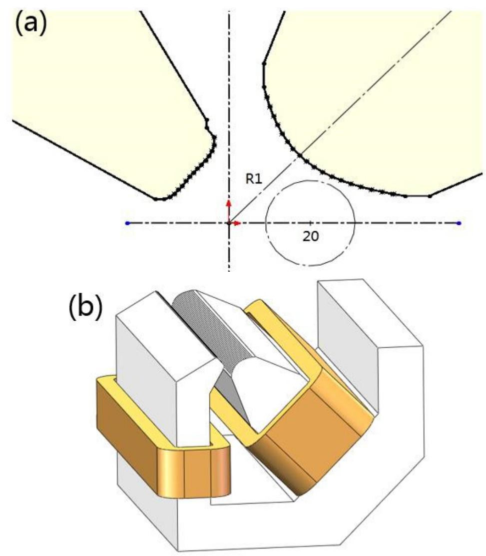

Figure 4: (a) Optimized pole profile and (b) Schematic diagram of DQ magnet.

The multipole fields of DQ within ±3 mm are all below 5×10^{-5}, as shown in Table 3. The homogeneity of dipole and quadrupole field are shown in Figs. 5 and 6.

Table 3: Multipole Field of DQ

n	b_n/b_2	n	b_n/b_2
3	-5.35E-6	4	-4.85E-5
5	-9.54E-7	6	-1.56E-6

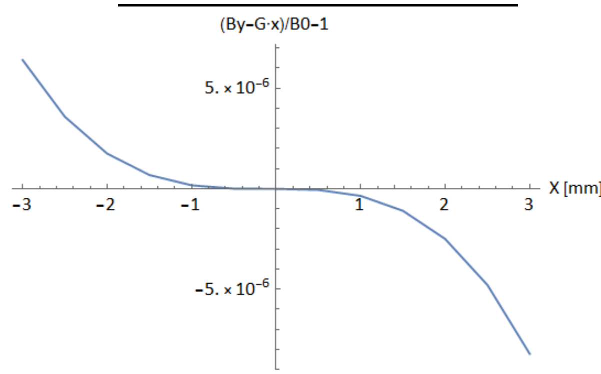

Figure 5: Homogeneity of field.

ISBN: 978-3-95450-207-3 doi:10.18429/JACoW-MEDSI2018-TUPH38

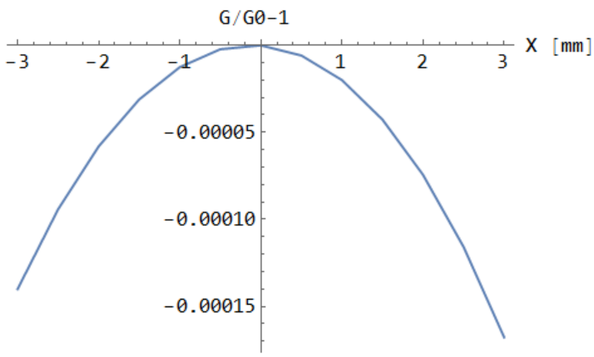

Figure 6: Homogeneity of field gradient.

Quadrupole

The initially proposed field gradient of the quadrupole was 90 T/m and recently it has been reduced to 80 T/m considering the technical risk. The optimized profile and schematic diagram of quadrupole magnet are show in Fig. 7. The gap between the adjacent poles is 11 mm, which can accommodate the beam antechamber or cooling water tube.

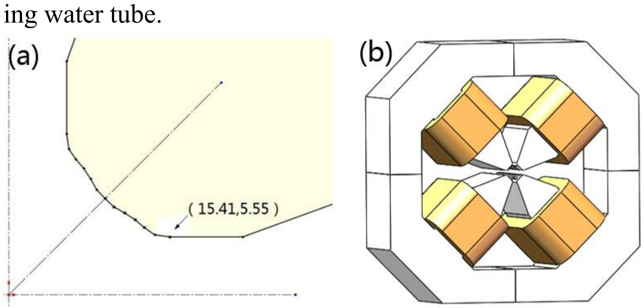

Figure 7: (a) Optimized pole profile and (b) Schematic diagram of quadrupole magnet.

The multipole fields of quadrupole within ±3 mm are all below 5×10^{-6}, as shown in Table 4. The homogeneity of quadrupole field within ±3 mm is better than 5×10^{-6}, as shown in Fig. 8.

Table 4: Multipole Field of Quadrupole

n	b_n/b_2	n	b_n/b_2
4	-4.84E-6	6	2.17E-6
8	7.57E-9	10	-2.56E-8

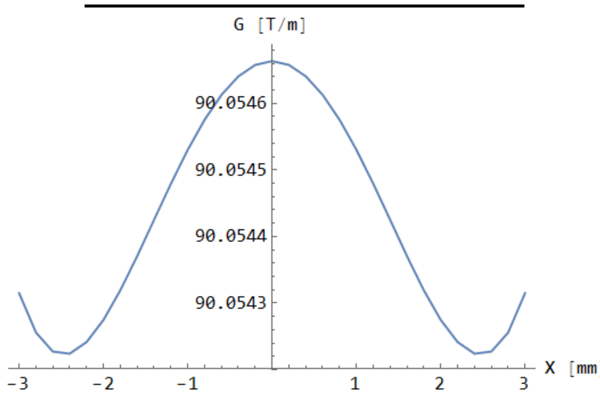

Figure 8: Homogeneity of quadrupole field.

Sextupole

The optimized profile and schematic diagram of sextupole magnet are show in Fig. 9. Because the small bore diameter, the pole width was about 6 mm and gap between adjacent poles was 7.74 mm.

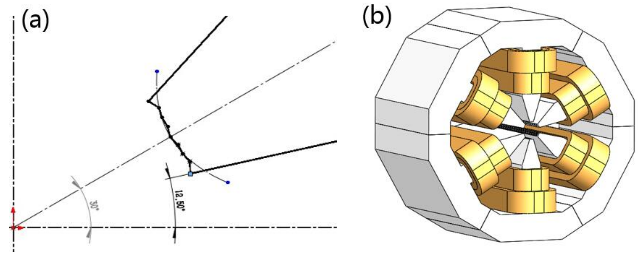

Figure 9: (a) Optimized pole profile and (b) Schematic diagram of sextupole magnet.

The multipole fields of sextupole within ±3 mm are all below 2×10^{-7}, as shown in Table 5. The homogeneity of quadrupole field within ±3 mm is better than 1.5×10^{-4}, as shown in Fig. 10.

Table 5: Multipole Field of Sextupole

n	b_n/b_2	n	b_n/b_2
9	-2.08E-7	15	-3.77E-9
21	3.01E-14	27	5.33E-15

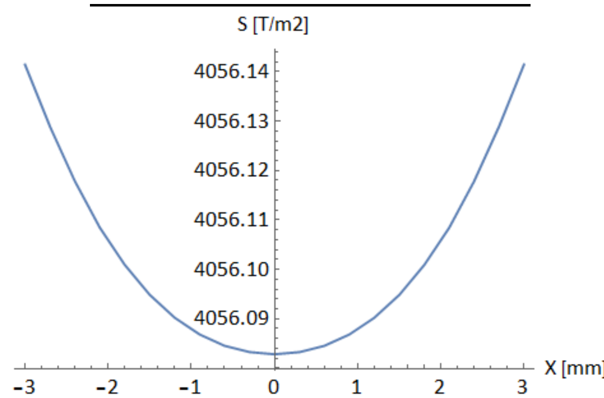

Figure 10: Homogeneity of sextupole field.

CONCLUSION

Preliminary design of the HALS magnets, including longitude gradient dipole, combined dipole quadrupole, quadrupole and sextupole have been carried out. Permanent magnet dipole was adopted because of its low operation cost. Other magnets are all traditional electromagnet and their pole profiles were optimized to obtain better field quality. More detailed research and engineering design will be performed next.

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