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DESIGN OF LONGITUDINAL GRADIENT BENDING MAGNET OF HALS

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Abstract

Hefei Advanced Light Source (HALS) is a diffraction limited light source, which was proposed and expected to be built in the next few years by National Synchrotron Radiation Laboratory (NSRL) of China. Just like other new light sources, longitudinal gradient bending magnet (LGB) will be adopted to suppress the beam emittance. The magnet consists of 7 modules with different magnetic field. Each module has yoke and poles with the same size but different amount of permanent magnet to generate field gradient. FeNi alloy is used to shunt magnetic flux and thus improve the temperature stability. Corrector coil or movable wedge can be used to adjust the field. Impact of magnetization direction error of permanent magnet block and parallelism error of poles on multipoles is also evaluated.

INTRODUCTION

Hefei Light Source (HLS) is a dedicated second generation light source, which was constructed by NSRL in the 1980s. To improve the performance of HLS, the upgrading project of HLS was implemented in 2010~2014 and the new light source was called HLS-II [1]. The storage ring of HLS-II was completely new and DBA lattice was adopted instead of TBA. However, with the development of the fourth generation light source, HLS-II is still can't meet the requirements from synchrotron radiation users. Therefore, to enhance the competitiveness of NSRL and better serve the synchrotron user community, Hefei Advanced Light Source (HALS) was brought forward a few years ago. At present, pre-study project of HALS is in progress to overwhelm the critical technique problems [2].

The HALS project aims to reduce the beam emittance close to the limit of diffraction and to improve the brilliance and coherence of the X-ray beams. Various designs philosophy and technologies are being studied and will be applied in HALS, such as lattice design, ultra-high vacuum and demanding magnets. Different types of magnets, including longitudinal gradient bending magnet (LGB), combined function dipole-quadrupole, high gradient quadrupoles and sextupoles, are used to decrease the beam emittance. Among them, LGB magnets were not commonly used in the past. Detailed design and some engineering consideration are presented in this contribution.

MAGNET PARAMETERS

The LGB magnet can be divided into 7 modules along the beam direction, with fields ranging from 0.29 to 0.689 T, as shown in Fig.1. Main parameters of LGB are listed in Table 1.

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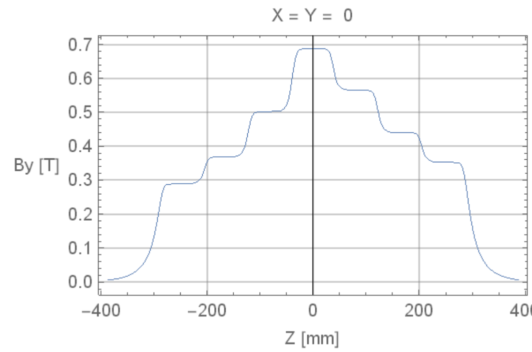

Figure 1: The fields of LGB versus longitudinal position.

Table 1: Main Parameters of LGB

Field integral	0.275 T·m
Magnetic length	0.6 m
Pole gap	26 mm
GFR	5 mm
ΔB/B	5×10^{-4}

MAGNET DESIGN

Permanent magnets have drawn more attention in particle accelerator area in recent years, because no electricity and cooling water are needed and so the operation cost can be reduced dramatically [3]. Therefore, permanent magnet (PM) design was adopted for the LGB.

Field Calculation

Each module of the LGB has pole and yoke with the same size, as shown in Fig. 2, but is magnetized by different amount of permanent magnet, so gradient magnetic field shown in Fig. 1 can be obtained. The remanence of permanent materials decrease with the increasing temperature. The temperature coefficients of commonly used Sm2Co17 and NdFeB are -3.5×10^{-4} and -1×10^{-3} respectively. Furthermore, Sm_2Co_{17} has higher resistance to radiation damage, so it is selected as the permanent material. The material of poles and yokes are all soft iron. For the ease of installing of vacuum chamber, the gap of the upper and lower pole is not less than 26 mm. Shape of poles and PM magnets are all regular cubes with chamfer on their edges.

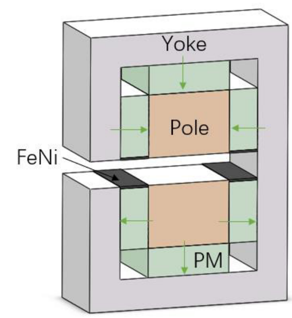

Figure 2: One module of LGB.

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The longitudinal gap of each module is 5 mm, so the seven modules especially two adjacent modules are coupled. In another word, change of the size of magnet blocks in one module will lead to the changes of fields in other modules. So the sizes of the magnet blocks have to be iteratively determined, as shown in Fig. 3. The difference of calculated and desired field of each module will be on the order of 1×10^{-4} after iteration.

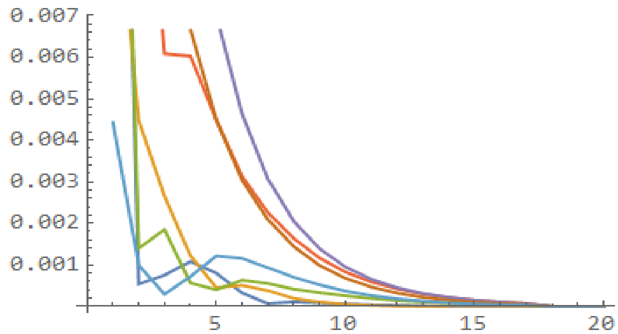

Figure 3: Difference of calculated and desired field of each module versus iteration number.

The field quality is mainly depent on the pole shape. In this design, the pole width is 80 mm and no shape optimization was implemented. Relative integrated field error ΔBL/BL within ±5 mm is about 3×10^{-4}, as shown in Fig. 4. The multipoles of LGB are listed in Table 2. The highest multipole is b3 = -1.86E-4.

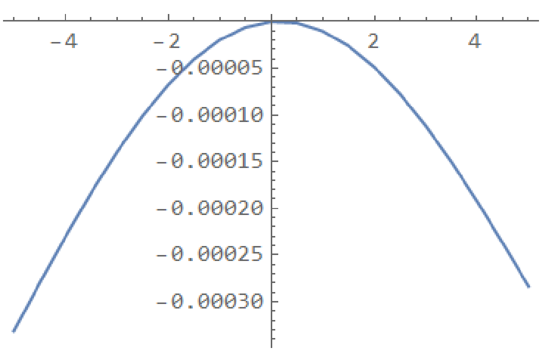

Figure 4: Relative integrated field error of LGB.

Table 2: Multipoles of LGB

n	b_n/b_1	n	b_n/b_1
2	1.19E-5	5	-3.47E-5
3	-1.86E-4	6	6.68E-8
4	1.42E-7	7	1.72E-6

Temperature Compensation

Temperature compensation is necessary for PM magnets to insure good temperature stability. A passive compensation system based on FeNi shunt is adopted. FeNi has high temperature coefficient of magnetic permeability. It means that when temperature increases, remanence of PM magnets decreases and the FeNi strip shunts less magnetic flux. So the fields can be more stable due to the shunt of FeNi strip. Each module has 4 FeNi strips attached on the PM magnets, as shown in Fig. 5.

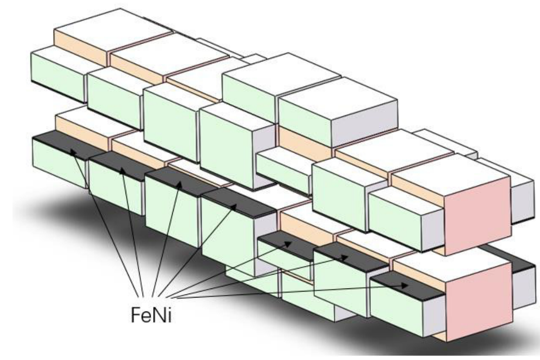

Figure 5: FeNi strips attached on the PM magnets.

Field Tuning

Because the field of LGB can deviate from the desired value due to many reasons, it's very attractive and useful if the fields can be tuned within a reasonable range. Two methods were considered: correction coil and movable wedge, as shown in Fig. 6 and Fig. 7.

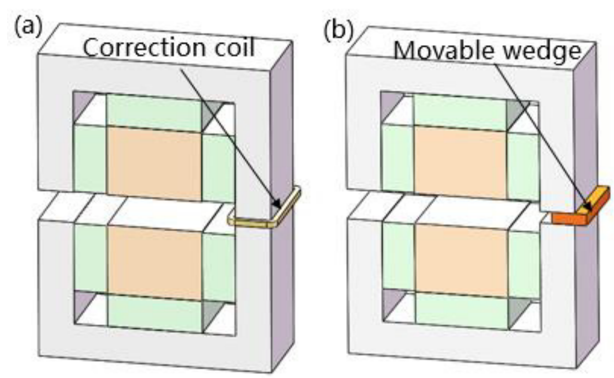

Figure 6: (a) Correction coil (b) Movable wedge used to tune field.

In the first method, a correction coil is installed on the center of the yoke. The precision of adjustment is about 1 Gauss/A·Turn. Dozens of ampere-turns are needed to obtain a tuning range of ±2%. The current density is not high, so solid copper wire can be used. The drawback of this method is additional DC power supplies are needed.

In the second method, a wedge can be translated horizontally in the gap of the upper and lower yoke. The magnetic resistance will change with the position of the wedge and so the field between the poles can be tuned. The precision of adjustment is about 15 Gauss/mm. No power supplies are needed but a linear motion mechanism to drive the wedge has to be taken in account in this method.

RANDOM ERROR

For PM magnets, random errors can be attributed to many factors, such as the mechanical errors of poles (translation and rotation error), magnetization direction and magnitude of PM blocks. Only the magnetization direction error of PM block and parallelism error of poles are considered here, as shown in Fig. 7. The actual angle of each pole or magnetization direction of PM block is assumed uniformly distributed within the error range. Monte Carlo

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method is used to conduct random sampling and stand deviation of the multipoles can be obtained according their probability distribution.

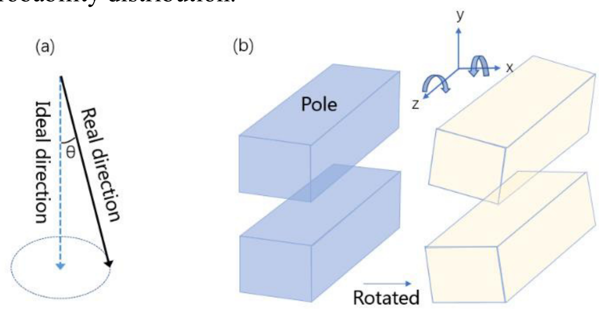

Figure 7: (a) Magnetization direction error of PM block; (b) Parallelism error due to rotation of poles.

Stand deviation of the multipoles induced by magnetization direction error of 50 and 100 mrad (2.86° and 5.73°) are shown in Fig. 8. It can be inferred that the impact of magnetization direction error on the multipoles is not significant, and errors of a few degrees are acceptable.

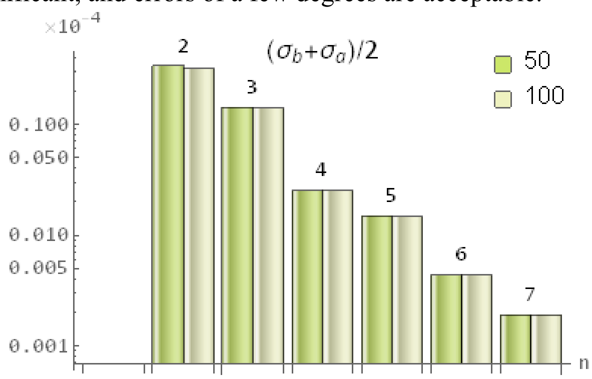

Figure 8: Stand deviation of the multipoles induced by magnetization direction error of 50 and 100 mrad.

Stand deviation of the multipoles induced by parallelism error of poles of 5, 10 and 15 mrad (0.3°, 0.6°, 0.9°) are shown in Fig. 9. The highest multipole under all conditions are b_2, which is on the order of 1×10^{-4}. So the parallelism error of poles should be kept as low as possible.

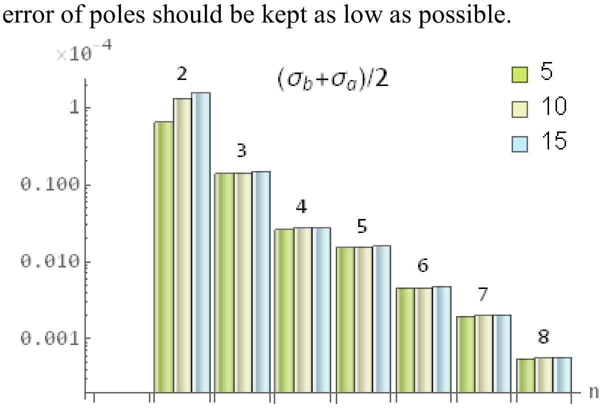

Figure 9: Stand deviation of the multipoles induced by parallelism error of poles of 5, 10 and 15 mrad.

CONCLUSION

LGB magnet was rarely used in the past, but is critical for the new generation synchrotron light source to suppress the beam emittance. The design of LGB of HALS, including temperature compensation, field tuning, impact of angle error of pole and PM block on multipoles are introduced in this paper. Detailed engineering design is ongoing and the prototype will be delivered in the end of this year (2019).

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