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DESIGN OF THE LONGITUDINAL GRADIENT DIPOLE MAGNETS FOR HALF*

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Abstract

Hefei Advanced Light Facility (HALF) is the fourth generation diffraction-limited storage ring light source project in China. The lattice of the storage ring consists of six different dipoles with longitudinal gradients. The longitudinal-gradient dipoles (LGBs) are permanent magnets. This paper presents the designed construction of LGBs and the magnetic field results using OPERA3D. By optimizing the shape of the polar surface, the magnetic field uniformity is optimized to about 5×10^{-4}. With some movable adjusting block, the magnetic field can be controlled accurately. The temperature stability of the magnet is better than 0.0074 T*mm/°C by setting temperature compensating shunt.

INTRODUCTION

Hefei Advanced Light Facility (HALF) is a soft X-ray diffraction-limited storage ring project at NSRL. The electron beam energy is chosen to be 2.2 GeV. Its total length is 480 meter, consists of 20 identical hybrid six-bend achromats (6BAs) [1]. With this lattice, the emittance of HALF is 85 pm·rad. Longitudinal-gradient dipoles (LGBs) are the key components for the HALF since it can be used to reduce the emittance of the storage ring beam. There are three LGBs with the same gap 26 mm. Each of them is divided into five segments (called modules). In one period, there are two LGB1 blocks and the distribution of field is symmetrical about the center of period. And so as the LGB2. LGB3 has a higher magnetic field than others, and the magnetic field of the central module is 1.3 T. It is difficult for the physical design of this Longitudinal-gradient dipole.

MAGNET DESIGN

Each Longitudinal-gradient dipole (LGB) consists of five modules with different magnetic field. The parameters of LGBs are shown in Table 1 and the specific magnetic field of each LGB is shown in Table 2.

Table 1: The Parameters of LGBs

	LGB1	LGB2	LGB3
Aperture	≥ 26mm	≥ 26mm	≥ 26mm
Effective Length	1.05 m	1.05 m	0.59 m
Good Field Region	±10 mm	±8 mm	±8 mm
Field uniformity	5×10^{-4}	5×10^{-4}	5×10^{-4}

Table 2: Specific Magnetic Field and Length of LGBs

	LGB1	LGB2	LGB3
Module1	0.55 T	0.32 T	0.48 T
	0.21 m	0.21 m	0.15 m
Module2	0.42 T	0.43 T	0.78 T
	0.21 m	0.21 m	0.11 m
Module3	0.32 T	0.58 T	1.3 T
	0.21 m	0.21 m	0.07 m
Module4	0.24 T	0.79 T	0.78 T
	0.21 m	0.21 m	0.11 m
Module5	0.18 T	0.65 T	0.48 T
	0.21 m	0.21 m	0.15 m

Figure 1 shows the structure of LGB1. It is mainly composed of iron poles, iron yokes, Sm2Co17 blocks, adjustable iron blocks and temperature compensation shunt sheets. In the modules of LGB1 and LGB2, different magnetic field intensities are produced by filling different volumes of Sm2Co17 blocks [2]. To produce a higher magnetic field, some N50SH blocks are filling in the module P3 of LGB3. Figure 2 shows the structure of LGB3. Adjustable iron blocks are installed between the upper and lower permanent magnetic blocks. As the blocks move horizontally, the magnetic field decreases and increases correspondingly. Temperature compensation shunt sheets are made of FeNi alloy. The flux shunt through the FeNi alloy has a higher temperature coefficient than that of Sm2Co17 and N50SH [3]. By adjusting the thickness of FeNi alloy sheets, it is possible to compensate the weaker temperature dependence of a larger volume of Sm2Co17 and N50SH. The degree of temperature compensation is linearly related to the amount of compensator material in the magnet.

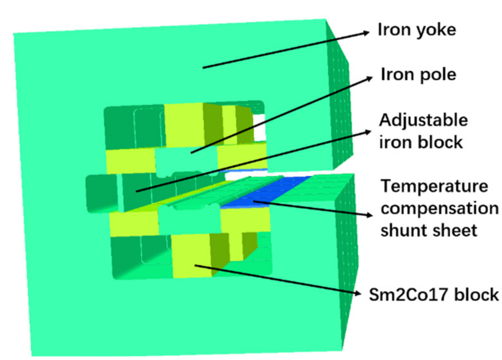

Figure 1: The structure of LGB1.

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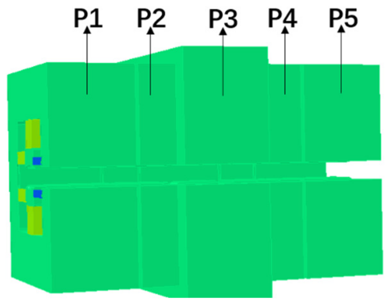

Figure a: Configuration of LGB3

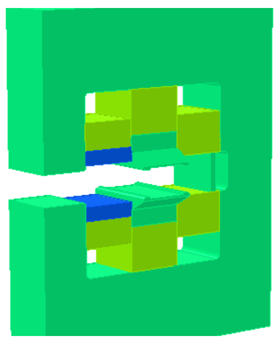

Figure b: Polar surface shape of P2

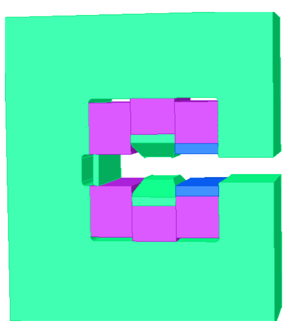

Figure c: Polar surface shape of P3

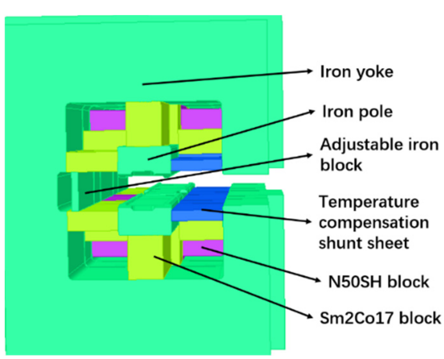

Figure d: Structure of LGB3

Figure 2: Detailed structure of LGB3 (Figs. 2(a-d)).

For the dipole, the field uniformity in the required good field region can be improved by adding excess pole beyond the edge of the good field region, which is called the pole overhang. The expression for the potential field quality and the pole overhang required to achieve a specified field quality for an optimized pole is [4]:

$$x_{ov} = \frac{a}{h} = -0.14 \ln \frac{\Delta B}{B} - 0.25 \qquad (1)$$

Both LGB1 and LGB2 use this method to design and optimize the pole shape.

As for the LGB3, the magnetic field requirement of module P3 is the highest, and needed 1.3 Tesla in a short range. The poles of module P2 and module P4 are designed as a step structure to avoid field drop between modules. In order to improve the magnetic field of module P3, the magnet is the special for optimization as follows:

- A sharp tip pole of module P3 focus the flux and improves the field.
- Using N50SH blocks instead of Sm2Co17 blocks to increase the magnetic field.
- Increasing the longitudinal length of module P3 properly to reduce the impact of P2 and P4 on the central magnetic field of P3.

After the optimization, the longitudinal field distribution and the better uniformity of good field area can be obtained. The results are shown in Figs. 3 and 4.

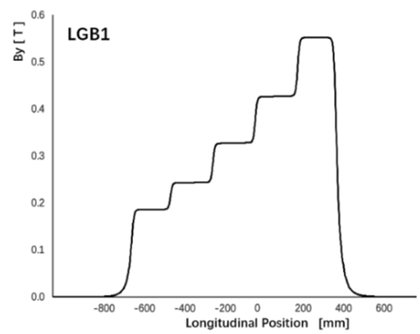

Figure a: Longitudinal field distribution of LGB1

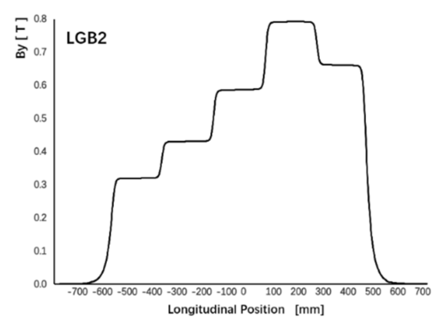

Figure b: Longitudinal field distribution of LGB2

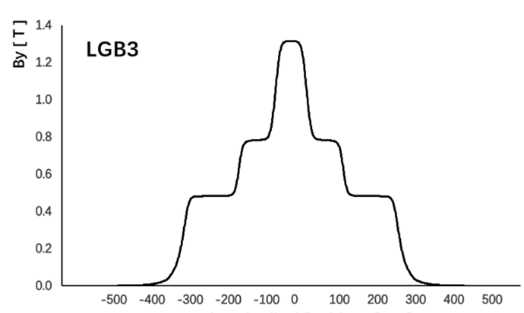

Figure c: Longitudinal field distribution of LGB3

Figure 3: Longitudinal field distribution of LGBs (Figs. 3(a-c)).

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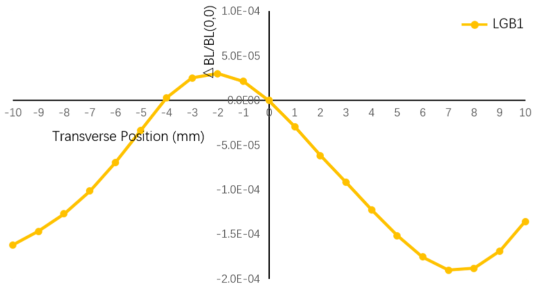

Figure a: Uniformity of Good field region of LGB1

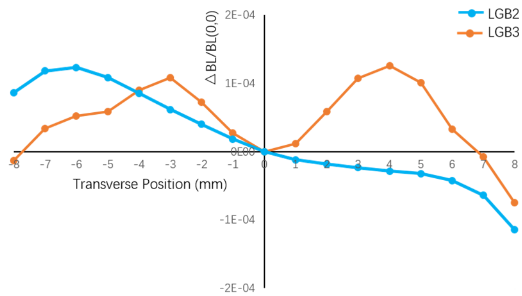

Figure b: Uniformity of Good field region of LGB2 and LGB3

Figure 4: Uniformity of Good field region of LGBs (Figs. 4(a) and 4(b)).

The parameters of the well-designed LGBs are shown in the Table 3.

Table 3: The Parameters of the Well-Designed LGBs

	LGB1	**LGB2**	**LGB3**
Physical Length	1.018 m	1.005 m	0.552 m
Integral field value (T*mm)	581.7	359.1	406.6
Field uniformity	2.5×10^{-4}	2.3×10^{-4}	2×10^{-4}

CONCLUSION

The physical design of LGBS has been completed. Considering the possible mechanical errors caused by the practical design, some allowance has been reserved at the beginning of the design. These physical models can be used to guide the actual manufacturing process of magnet mechanical elements and has practical value.

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