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DESIGNS AND MEASUREMENTS OF A NEW SUPERBEND-MAGNET FOR WALS

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Abstract:

In order to provide hard X-rays with a 1.5 GeV electron ring, a new superbend-magnet will be used in the middle of each standard cell at Wuhan Advanced Light Source (WALS). The design, assembly, and detailed magnetic measurement of the superbend-magnet prototype has been finished. The results of magnetic measurement show that the central magnetic field reaches 3.67 T in a gap of 14.72 mm, and the range of high field region (＞3.5 T) is larger than 40 mm in the longitudinal direction. The uniformity of the field integral is controlled below 5×10^{-4} within the good field region. Two low-field magnets are designed as water-cooled resistive magnets which can be used to correct the integrated dipole and quadrupole components.

INTRODUCTION

Wuhan Advanced Light Source (WALS) is a 4th synchrotron radiation source which located in Wuhan, Hubei Province. The WALS 1.5 GeV storage ring has a perimeter of 180 m with 8 unit-cells and 7BA lattice structure is used to achieve lower emittance [1]. In each middle of the unit-cell, a new superbend-magnet will be used to provide hard X-rays. There are several different types of superbend magnets, such as electromagnet superbend [2,3], permanent magnet superbend [4], superconducting magnets superbend [5]. Considering the low energy consumption and stability of the superbend magnet, high-field permanent magnet combined with two low-field electromagnets was chosen for WALS. The design, assembly, and detailed magnetic measurement of the superbend-magnet prototype are described carefully in this paper.

In section II, 2D/3D physical designs with Poisson and OPERA are described carefully. Section III describes the mechanical design and assembling process of superbend magnet. Detailed magnetic measurement of the superbend-magnet prototype has been finished and results are presented at section IV. Finally, section V gives a brief conclusion.

PHYSICAL DESIGN

Since the longitudinal space is highly squeezed, Superbend magnet is designed as a three-stage combined magnet with a high-field permanent magnet in the middle and two low-field electromagnets with transverse gradient on each side. The detailed parameters are showed in Table 1.

Table 1: Superbend Magnet Main Parameters

High-field permanent magnet	
Number per cell	1
Maximum field (T)	3.67
Gap(mm)	15
Core length (mm)	200
Critical Photon Energy (keV)	15
Magnetic Material	Nd-Fe-B
High Field Pole Material	Fe-Co-V
Low-field electromagnets	
Number per cell	2
Magnetic field (T)	0.91
Transverse gradient(T/m)	-19.8
Gap(mm)	28
Core length (mm)	140
Total	
Overall length(mm)	600
Bending angle (°)	9.8
Integrated field (T·m)	0.8284
Integrated gradient (T)	-9.22
GFR (mm)	±6 H, ±5 V
Field integral uniformity (ΔBL/BL)	＜5×10^{-4}

The electromagnets on two sides are gradient dipoles with a centre field of 0.91T, so the pole shapes are designed as half of a normal quadrupole to produce enough fields. The iron blocks at the opening sides are used to adjust the homogeneity of the field integrals. A magnetic DT4 iron block is placed on the other side to optimize the uniformity of the magnetic field distribution. It's a new magnetic center where the point is at $X=B_0/G_0$. Here B_0 and G_0 are the center magnetic field and the transverse gradient of the low-field electromagnet respectively. 2D physical model has been designed by Poisson and is shown in Fig. 1. All multipoles errors are under 5×10^{-4} within the good field region of magnetic field.

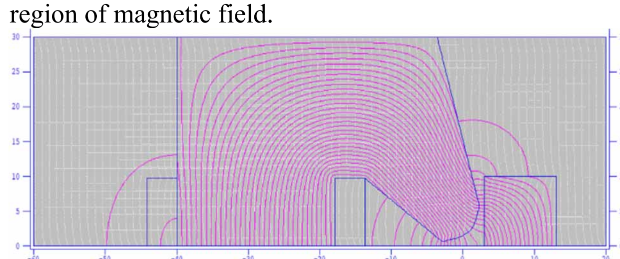

Figure 1: 2D magnetic physical design of the low-field electromagnet by Poisson.

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To obtain the strong fringe field effects on the field integral homogeneity, the 3D simulations are performed via OPERA3D [6]. Fig. 2 shows the high-field permanent magnet model (left) and the three-stage combined magnet model (right). The 3D calculations show that 3.7 T magnetic center field can be reached when only high-field permanent magnet model is calculated and 3.67 T magnetic center field can be reached while simulating the three-stage combined magnet model. According to the calculation results, the uniformity of the field integral is controlled below 5×10^{-4} across the good field region, and length of longitudinal flat top area reaches approximately 20 mm.

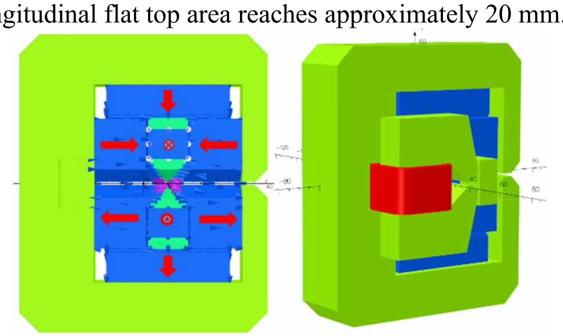

Figure 2: The high-field permanent magnet model (left, blue areas are Nd-Fe-B permanent magnet block with arrows indicating directions of magnetization) and the three-stage combined magnet model (right).

MAGNET ASSEMBLY

Two low-field magnets are designed as water-cooled resistive magnets and composed of DT4 iron cores, coils, magnetic DT4 iron blocks and a support. They were pre-assembled before permanent magnet.

The high-field permanent magnet consists of magnetic yokes, Fe-Co-V high field poles and more than 5000 permanent magnetic blocks. All permanent blocks are arranged to place around the Fe-Co-V poles elaborately and shown in Fig. 3.

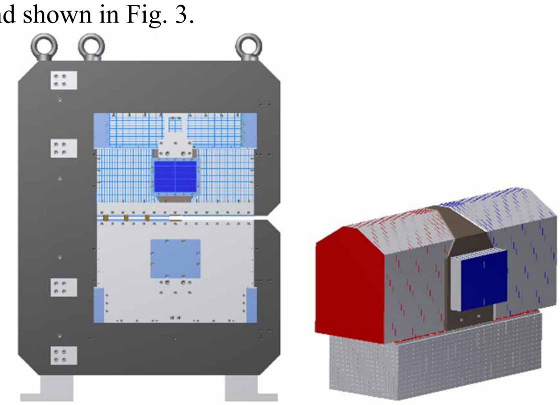

Figure 3: Arrangement of permanent magnetic blocks around the pole.

Assembly process of the Permanent Magnet Superbend [4] in the Sirius Light Source has been taken as a reference and there are four steps to complete this hard assembly. In the first step, permanent magnetic blocks on the bottom of the yokes were assembled by aluminium guides and fastened with metal glue. Figure 4(a) shows this assembly process. In the second step, poles are placed in the yokes by aluminium guides transversely and this step is shown in Fig. 4(b). Thirdly, permanent magnetic blocks are filled in turn carefully on each side of the poles. Well-designed toolings were utilized due to the strong magnetic force between those blocks and shown in Fig. 4(c) and 4(d).

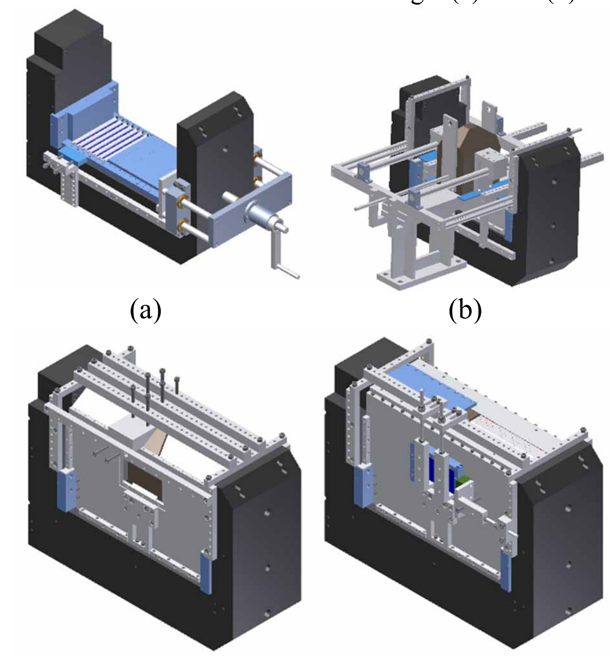

Figure 4: Assembly process of the high-field permanent magnet.

In the last step, two half yokes are joined using the aluminium guides and a crane. The gap dimension is controlled by a thickness-adjustable steel pad. In this phase, it's a quite difficult since the strong magnetic attractions between two parts reach greater than 8 tons! In order to ensure the height and parallelism of the gap, a huge iron stand column fastens two yokes and a steel plate is placed in the inner side of the yokes.

Finally, two low-field magnets are placed on each side separately. This step is also dangerous due to the magnetic force and should be assembled carefully using special devices. After assembly, the whole magnet is shown in Fig. 5.

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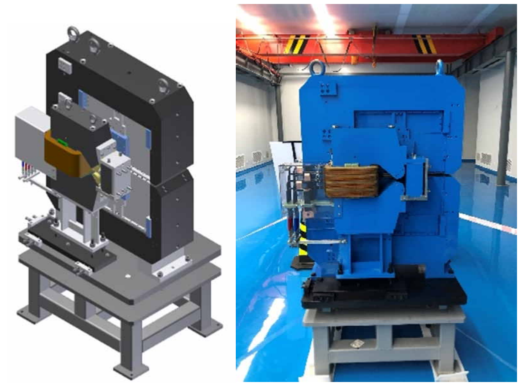

Figure 5: Well-assembled superbend magnet. The mechanical design is on the left and picture of real magnet is on the right.

MAGNETIC FIELD MEASUREMENT

The magnetic field distribution of this magnet has been measured since April 2021 by both a Hall probe measurement system and a moving long double-coils measurement system.

Figure 6: Superbend magnet being measured by a Hall probe measurement system.

A Hall probe with maximum range of 6 T was used to measure the magnetic center field which reaches 3.5 T above. Figure 6 shows the Hall probe system measuring the superbend magnet prototype.

The results of magnetic Hall probe measurement show that the central magnetic field reaches 3.67 T in a gap of 14.72 mm, and the range of high field region (>3.5 T) is larger than 40 mm in the longitudinal direction, forming a flat top area of approximately 20 mm. Figure 7 shows the magnetic field along the longitudinal profile.

Detailed magnetic measurements were performed to check the uniformity of the field integral by a moving long double-coils measurement system. There are two PCB coils in the skeleton. To make the signals of the higher order harmonics obvious, the two coils need to compensate both dipole and quadrupole fields, so they are connected in series reversely. The uniformity of the field integral is controlled below 5×10^{-4} within the good field region of transverse ±6 mm and is shown in Fig. 8.

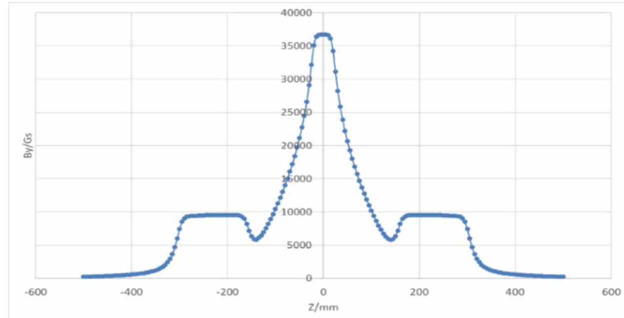

Figure 7: The magnetic field of the superbend magnet along the longitudinal profile.

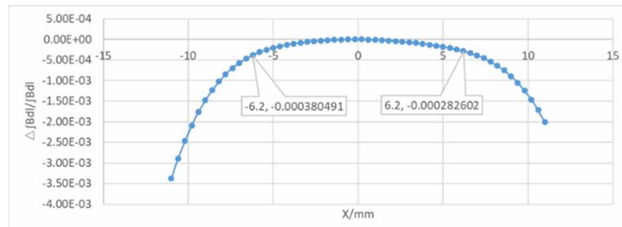

Figure 8: The uniformity of the field integral distribution in the mid-plane of the superbend magnet.

CONCLUSION

Special efforts are done in the 3D field optimization, the structure design and assembly for the superbend dipole of WALS. Assembly process has been finished even if it is a dangerous and hard task. Detailed magnetic measurement of the superbend-magnet prototype has been completed by using both high-precision Hall probe measurement system and a moving long double-coils measurement system. The results of magnetic measurement show that the central magnetic field reaches 3.67 T in a gap of 14.72 mm, and the range of high field region (>3.5 T) is larger than 40 mm in the longitudinal direction. The uniformity of the field integral is controlled below 5×10^{-4} across the good field region. In the further work, we plan to investigate the temperature compensation and demagnetization effects because of the beam radiation and vacuum baking.

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