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DESIGN OF THE MAGNETS OF THE HALS PROJECT#

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Abstract

The Hefei Advanced Light Source (HALS) is a future soft X-ray diffraction-limited storage ring at NSRL, 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, dipoles with longitudinal gradients (DLs), high gradient quadrupoles and strong focusing sextupoles. The combined dipole-quadrupole design developed is between the offset quadrupole and septum quadrupole types. The longitudinal-gradient dipoles are permanent magnets. The quadrupoles and sextupoles rely on a more conventional design. All the magnets have been designed using POSSION, Radia, and OPERA-3D.

INTRODUCTION

HLS-II is the upgrade project of Hefei light source (HLS). It has been operated for over three years, and the capability and performance of the light source has been improved a lot. However, HLS-II is lag behind, which can not meet the requirements of advanced synchrotron radiation activities, and the increasing demand from synchrotron radiation users and development of the fourth generation light source. To enhance competition of NSRL, a scheme of new soft X-ray light source was brought forward, which was named Hefei Advanced Light Source (HALS). At present, the electron beam energy is chosen to be about 2.0 GeV, and the beam emittance is aimed at below 50 pm·rad [1].

The HALS lattice relies on magnets with demanding specifications. To improve the brilliance and coherence of the X-ray beams and to decrease the horizontal emittance, not only a large number of low field dipole magnets with gradient field are needed, also stronger focusing. At the same time, strong chromatic sextupoles are necessary to compensate large natural chromaticity.

MAGNET DESIGN

The high quality magnets are one of the main challenges of the HALS lattice. The reduction of the beam size allows a significant reduction of the magnet apertures. The vertical distance between the poles of the magnets has been limited to at least 10 mm to allow the installation of the X-rays beam ports. The pole shape is designed to reach the required field quality of 5×10^{-4}, and the Good Field Region (GFR) have to reach 7 mm.

As shown in Fig. 1, an asymmetrical structure design has been selected for the DQ magnets (Fig. 1a). The DL magnets (Fig. 1b) are built with seven sub-magnet systems. The quadrupole magnets (Fig. 1c) and sextupole magnets (Fig. 1d) are obtained with a more conventional design.

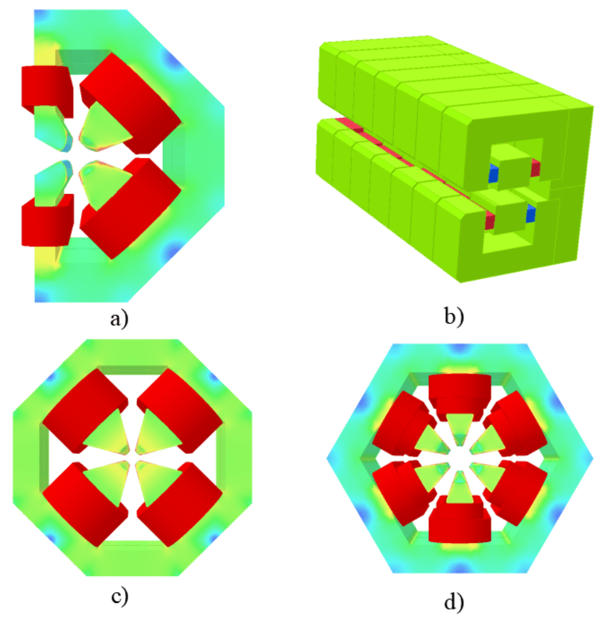

Figure 1: a) 3D model of DQ magnet, b) 3D model of DL magnet, c) 3D model of high gradient quadrupole, d) 3D model of sextupole magnet.

The location of this pole cutoff can be obtained with expressions [2]. To optimize the pole shape, a Gauss-Newton algorithm was used, and the optimization problem is linearized by computing the Jacobi matrix, and iterating a few times [3]. The 2D pole profile is simulated by using POSSION and Radia, while the 3D model by using Radia and OPERA-3D. The end chamfer is modelled to meet the field uniformity requirement.

Combined Dipole Quadrupoles (DQs)

The HALS lattice includes several types of DQs. The magnet aperture is 26 mm with a 7 mm GFR. The central field is $B_0 = 0.5$ T, while the gradient field is from 11 T/m to 25 T/m. In a conventional approach, the quadrupole field is generated by varying the gap along the transverse direction, which also called tapered dipole design, but this design lead to poor field quality in the low field area of the magnet bore: additional iron parts are needed for ensuring a linear decrease of the field [4]. High gradient field DQs can be obtained with a offset quadrupole design, but this design will increase the magnet size and power consumption.

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Finally, the DQ design developed is in between the offset quadrupole and septum quadrupole types [5]. The pole radius and the coil on the low field side have been reduced, meanwhile the power consumption can be lowered down. This design can lighten the magnet weight and simplify the vacuum chamber design [6].

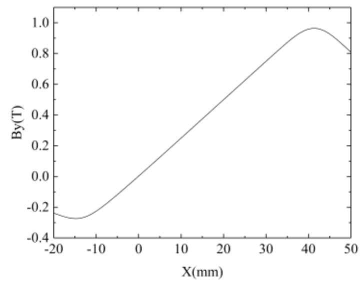

Figure 2: Magnet field of the DQ1.

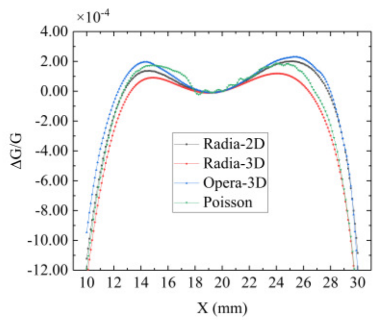

Figure 3: Relative gradient error of the DQ1 magnet.

The central field of DQ1 is 0.5 T, and it's the gradient field is 25 T/m. The magnetic field of the DQ1 is shown in Fig. 1b, and relative gradient error of the DQ1 magnet presents in Fig. 3. The magnet center is located at x = 20 mm, while x = 0 is the center of the ideal hyperbola. The maximum field on the non-used side is reduced to less than one third of the used side. The inhomogeneities of the gradient are in the range of 5×10^{-4} for the GFR of 8 mm.

Longitudinal Gradient Dipoles(DLs)

The DL magnet select a permanent magnet design, and it's built with seven sub-magnet systems called modules. There are two types of modules (Fig. 4a), and the low field modules have removed two blocks of PM material and its mechanical design also has been modified. The gaps and the pole shapes of the modules are all the same, and the modules are filled different amounts of permanent magnet volumes to achieve the longitudinal field gradient. The length of each module is 81.6 mm, and the vertical gap is 29.4 mm. With a longitudinal gap of 4.8 mm between two modules, the overall length of DL is 600 mm.

The PM material used for the DL is Sm_2Co_{17} due to its resistance to radiation damage and its temperature stability [7]. Up to now, no demagnetization of Sm_2Co_{17} in vacuum undulators has been observed [4]. The temperature coefficient of Sm_2Co_{17} is $\Delta B_r/B_r = -3.5\times10^{-4}$, about one third of the coefficient of $Nd_2Fe_{14}B$ material. Pure iron is used for the yoke and the pole. The pole shape is designed to reach the required integrated field quality $\Delta\int Bdz/\int Bdz$ of 5×10^{-4} in the region of -7 mm ≤ x ≤7 mm.

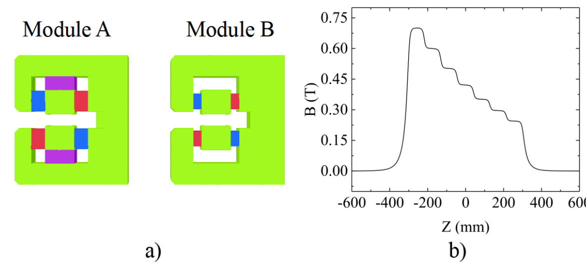

Figure 4: a) Two types of modules, b) Field versus longitudinal position.

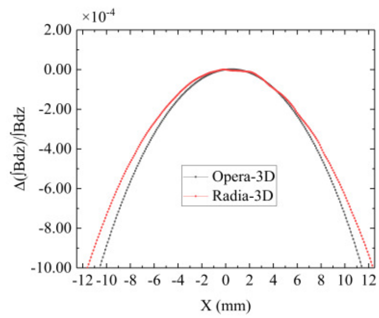

Figure 5: Relative integrated gradient error of the DL magnet.

The vertical field along the DL is shown in Fig. 4b, and Fig. 5 shows the relative integrated field error of the DL magnet. In order to meet the integrated field uniformity requirement, a large pole width design has been selected, as it's difficult to be obtained with end chamfer. There are seven modules in the DL magnet, and the modules are very close to each other. There will be a significant cross talk effect between two modules, and it will be studied in the near future.

Quadrupole Magnets

Two types of gradient quadrupoles will be installed at the HALS lattice: high gradient (HG) quadrupoles (70T/m~80T/m) and moderate gradient (35T/m~51T/m) quadrupoles. All the quadrupoles are iron dominated normal conducting magnets. The moderate gradient quadrupole works below the saturation and its field quality is independent from the magnet current, while the working point of high gradient quadrupole is closer to saturation and the field quality has been optimised at this working point. All the quadrupoles have the same bore diameter of 26 mm, determined by the vacuum chamber.

With pole radius and required good field region defined by the radius, the location of the pole cutoff point can be obtained [2]. The pole shape has been optimized using the tools mentioned above to reach required field quality $\Delta B/B$ of 5×10^{-4} in the GFR of 7 mm, and the pole shape of different gradient quadrupoles obtained with different optimization parameters. The 2D magnetic analyses have been performed using Radia and POISSON group

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computer codes. The field harmonics at the reference radius 7 mm are in the range of 3.2 unit. The 3D magnetic analyses have been performed using Radia and OPERA-3D group computer codes, and the integrated field uniformity meet the requirement.

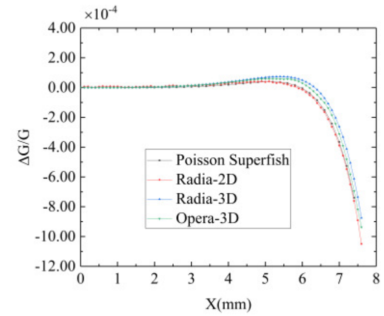

Figure 6: Relative gradient error of the HG.

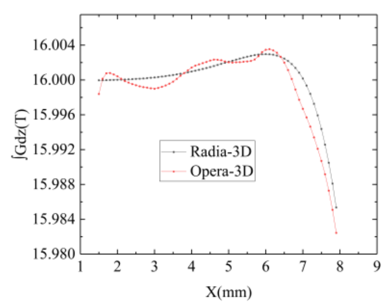

Figure 7: Integrated gradient field of the HG.

The relative gradient error of the high gradient quadrupoles is shown in Fig. 6, and Fig. 7 shows the integrated gradient error of the high gradient quadrupoles.

Sextupole Magnets

The HALS lattice includes several types of sextupole magnets, and the maximum sextupoles strength will reach 4000 T/m^2. A more conventional design has been selected for the strong sextupole magnets. The sextupole magnets are designed with a 15 mm pole tip radius and a 9 mm vertical gap between the poles. All the sextupoles are iron dominated normal conducting magnets, and the working point of the sextupole is below saturation.

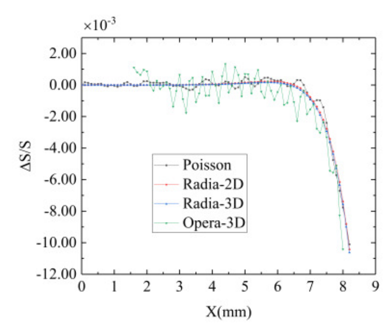

Figure 8: Relative sextupole field error of the sextupole magnet.

The pole shape has been optimized to meet the field uniformity requirement of 5×10^{-3}, and Fig. 8 shows the relative sextupole error of the sextupole magnet. As shown in Fig. 9, the integrated sextupole field error is below 5×10^{-3} at the reference radius 7 mm. The integrated magnetic field harmonics at the reference radius 7 mm are in the range of 1 unit.

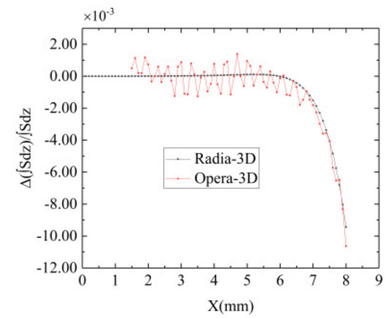

Figure 9: Relative integrated sextupole field error of the sextupole magnet.

CONCLUSION

The physical design of magnets was finished for the Hefei Advanced Light Source. Combined function dipole-quadrupoles with a quadrupolar field on one side and a low field on the other side enable easier installation of vacuum chambers, lower power consumption and facilitate magnetic measurements. It is foreseen to install PM dipoles with longitudinal gradients. These magnets are very compact and have zero power consumption. Quadrupoles with gradients as high as 80 T/m have been designed. A conventional design is chosen for strong sextupoles. All magnets are simulated in POSSION, Radia and OPERA-3D, and the poles shape has been optimized to meet the field uniformity requirement.

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