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THE LIMITED B-FIELD INTEGRAL OF SUPERCONDUCTING LONGITUDINAL GRADIENT BEND MAGNET*

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Abstract

The National Synchrotron Radiation Laboratory (NSRL) is planning a fourth generation diffraction-limited light source–Hefei Advanced Light Source (HALS), it is based on a seven-bend achromat lattice providing an ultralow natural emittance of 34 pm rad [1]. The emittance can be even lower with the use of longitudinal gradient bends (LGBs) and anti-bends (ABs). The designed energy for HALS is 2.4 GeV, superconducting LGB might be employed instead of normal bending magnet since it can improve radiated beam critical energy to hard x-ray regions without using up any straight sections [2]. To get a peak field about 6 T and small B-field profile full width half maximum, SLS-2 type LGB is considered [3]. In this paper, the limited B-field integral (along the beam path) is trying to be find with some restrictions.

INTRODUCTION

To simplify the simulation calculation, B-field is fully produced by coils without iron yoke. The structure of four coaxial superconducting coils are shown in Fig. 1. The inner coils are racetrack-shaped and can provide the peak B-field, the outer coils are circular and are used to guarantee the vertical B-field along the beam path would not reduce to negative within the longitudinal magnet length. In consideration of the immaturity of high temperature superconducting strands, $NbTi$ and Nb_3Sn strands will be used for outer and inner coils individually. When the vertical distance between the two inner coils and the peak vertical B-field are determinated, the vertical B-field integral can be adjusted by changing the cross profile of inner and outer coils. The focus of my work is to find its minimum value considering the current density of superconducting strands and simple analysis is presented below.

APPROXIMATE CALCULATION

This type LGB can be described by 9 parameters: the radius r_{in}, the thickness t_{in}, the height h_{in}, the width w_{in} and the half horizontal length the inner coils; the radius R_{out}, the width W_{out}, the height H_{out} and the thickness T_{out} of

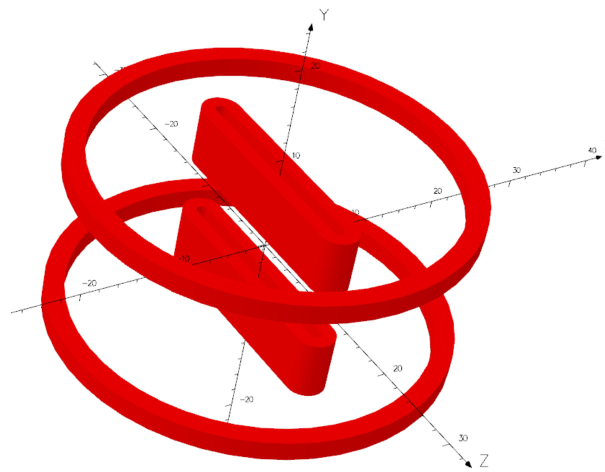

Figure 1: The structure of coils, beam travels along the Z-axis.

the outer coils. We can get the B_y along the beam path:

$$B_y(x) = \frac{\mu_0 J_{in}}{4\pi}\int_{r_{in}}^{r_{in}+w_{in}}\int_{h_{in}}^{h_{in}+t_{in}} B_{yin}(r,h,x)\,drdh + \frac{\mu_0 J_{out}}{4\pi}\int_{R_{out}}^{R_{out}+W_{out}}\int_{H_{out}}^{H_{out}+T_{out}} B_{yout}(R,H,x)\,dRdH \quad (1)$$

while

$$B_{yin}(r,h,x) = \int_{-l_{in}}^{l_{in}} \frac{x+r}{\left(h^2+(x+r)^2+z^2\right)^{3/2}}dz - \int_{-l_{in}}^{l_{in}} \frac{x-r}{\left(h^2+(x-r)^2+z^2\right)^{3/2}}dz + \int_0^{\pi} \frac{r\left(r-xcos\theta+lsin\theta\right)}{\left(h^2+r^2+x^2+l^2-2rxcos\theta+2rlsin\theta\right)^{3/2}}d\theta - \int_{\pi}^{2\pi} \frac{r\left(r-xcos\theta-lsin\theta\right)}{\left(h^2+r^2+x^2+l^2-2rxcos\theta-2rlsin\theta\right)^{3/2}}d\theta \quad (2)$$

and

$$B_{yout}(R,H,x) = \int_0^{2\pi} \frac{R\left(R-xcos\theta\right)}{\left(H^2+R^2+x^2-2Rxcos\theta\right)^{3/2}}d\theta \quad (3)$$

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But B_{yin} (B_{yout}) can't be figured out as polynomial equation of r and h (R and H), so the $B_y(x)$ is calculated approximately by dividing the coil cross profile into $1mm \times 1mm$ squares in this paper. Although the B-field can be easily calculated by Opera3D and other FEA software, the limited vertical B-field integral can't be find out quickly. Next part I will show my way to find the limited vertical B-field, but now the simulation result should be verified and analyzed with respect to the result of Opera3D. The inner coils and outer coils are calculated individually, and the result, comparing with Opera3D, is shown in Fig. 2. The picture shows that the simulation result is credible.

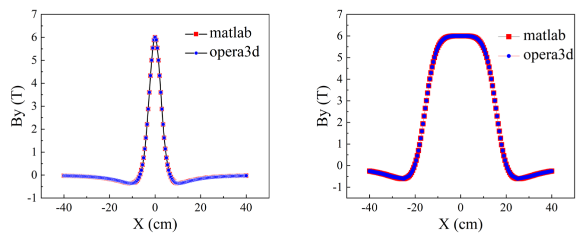

Figure 2: The parameters of inner coils are r_{in}=1, w_{in}=2, h_{in}=3, t_{in}=6, l_{in}=10 and R_{out}=15, W_{out}=2, H_{out}=7, T_{out}=2 for outer coils. The scale is centimeter.

ANALYSIS

The cross profiles of the coils are related to the limited vertical B-field integral obviously. To simplify the analysis, the inner coils and outer coils are simulated individually. For inner coils, w_{in}, h_{in}, t_{in} and l_{in} are constant, r_{in} is variable; for the outer coils, R_{out},W_{out},T_{out} are constant while H_{out} is variable. The vertical B-field along the beam path changes with r_{in} and H_{out} is shown in Fig. 3. It is obviously that r_{in} influences the FWHM significantly, and the lowest vertical B-field reduces with r_{in} increases. To get the diminishing positive B_y-field, H_{out} should be adjusted to

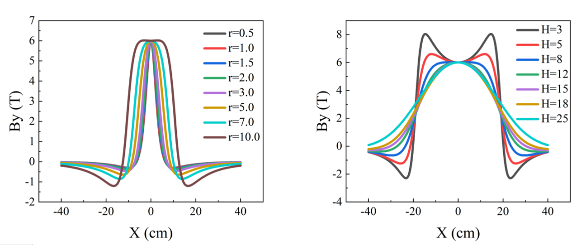

Figure 3: Vertical B-field along the beam path of inner coils (left) and outer coils (right).

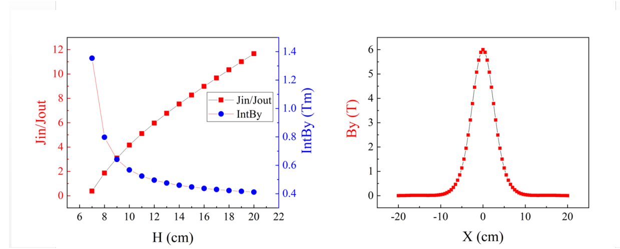

Figure 4: H means H_{out} here, the parameters of coils are same to Fig.2 except the changing H_{out}.

inner coils. When the parameters of inner coils are totally set, and $B_y|_{(x=-20)}$=0 T, $B_y|_{(x-0)}$=6 T, the current density of inner coils and outer coils are calculable with given outer coils' parameters. Figure 4 shows the changing of the integral of vertical B field along the beam path and J_{in}/J_{out} under the influence of the H_{out}. It seems that integral of B_y decreases with H_out increases, while actually the inner coils are working out of critical current density.

CONCLUSION

The B_y along the beam path can be changed by changing the cross profile of the coils. When the peak filed and the effective path integral are designed, there should be a mathematical minimum B_y integral. The method used in this paper is time-consuming since the integral of these two kind of coils can't be solved directly. So the attempt to find the minimum integral is simplified and incredible, but there should be other methods to find better result. The design of superconducting LGB magnets will be easier if the minimum integral can be calculated with restrictions. Further optimization of the method and calculation of the influence of iron yoke are under consideration.

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